LOG OF MEETING
DIRECTORATE FOR ENGINEERING SCIENCES

SUBJECT: Recreational Off-Highway Vehicles (ROVs) – Meeting requested by the Recreational Off-Highway Vehicle Association (ROHVA) to present testing done by ROHVA in the areas of lateral stability, vehicle handling and occupant protection performance.

DATE OF MEETING: November 10, 2011

PLACE OF MEETING: U.S. Consumer Product Safety Commission, Bethesda, MD

LOG ENTRY SOURCE: Caroleene Paul, ESME

COMMISSION ATTENDEES: See attached attendance list

NON-COMMISSION ATTENDEES: See attached attendance list

SUMMARY OF MEETING:

Representatives of the Recreational Off-Highway Vehicle Association (ROHVA) met with CPSC staff to discuss testing done by ROHVA in the areas of lateral stability, vehicle handling and occupant protection performance of ROVs.

CPSC staff opened the meeting by setting the following ground rules:

- ROHVA requested this meeting with CPSC staff so, although the meeting was public, discussions were limited to ROHVA representatives and CPSC staff/representatives.
- The opinions or views expressed by CPSC staff were not reviewed or approved by the Commission and may not reflect the views of the Commission.
- The discussions during the meeting will be treated as comments to the ongoing rulemaking and will become part of the public record.

ROHVA representatives presented testing performed by Carr Engineering, Inc. (CEI), Design Research Engineering (DRE), and Applied Safety and Ergonomics, Inc. Presentation is attached.

MEETING ATTENDANCE RECORD

ROHVA / CPSC Staff – November 10, 2011

COMMISSION ATTENDEES:

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RECREATIONAL OFF-HIGHWAY VEHICLE ASSOCIATION

ROHVA

ROHVA Update:
Standards Development and Safety Programs

Presented to
U.S. Consumer Product Safety Commission
Technical Staff
November 10, 2011

CPSC/SEA Objectives

1. OVERVIEW

This report contains results from measurements made by SEA, Ltd. for the Consumer Product Safety Commission (CPSC) under contract CPSC-S-10-0014. The objectives of contract CPSC-S-10-0014 are:

…accurate and repeatable…

- To document, study, and compare the dynamic performance characteristics of commonly available recreational off-highway vehicles (ROV's).

This report contains test results for measurements made on nine vehicles. All of the vehicles were selected by CPSC, and all of them can be classified as recreational off-highway vehicles (ROV's). They all have side-by-side seating, and they all use a steering wheel, brake pedal, and throttle pedal for operator control inputs. Eight of the vehicles tested were two-passenger vehicles (Vehicles A-H in this report), and one was a four-passenger vehicle with a second row of side-by-side seating (Vehicle I in this report). The measured curb weights (weights with full fluids and no occupants or cargo) of the vehicles ranged from 1025.0 lb to 1753.4 lb. The measured average maximum speeds of the vehicles ranged from 38.1 mph to 59.2 mph in a loading condition representing Operator plus Passenger loading.

Findings Summary

- SSF/K_{st} and TTA are static vehicle parameters that can be measured accurately and reliably as long as key test variables are defined and controlled

- J-Turn SWA and Ay are dynamic test parameters that cannot be reproduced accurately or reliably due to uncontrollable variations in specific methodologies

- On-highway steady-state steering characterization can be performed accurately and reliably, but can change dramatically when evaluated off-highway

Testing Performed

- **Static Evaluations**
  - ✓Static Stability Factor (SSF) Calculation
  - ✓Tilt Table Angle (TTA) for Two-Wheel Lift

- **Dynamic Evaluations**
  - ✓Drop-Throttle J-Turn Minimum SWA
  - ✓Drop-Throttle J-Turn Minimum Ay
  - ✓On-Highway Steering Characterization
  - ✓Off-Highway Steering Characterization

SSF

SSF Evaluation

- Measurement of CG and calculation of SSF using SAE suspension method (vs. SEA VIMF apparatus)

- Total of 44 individual configurations evaluated
  - ✓Eleven machines
  - ✓Four loading configurations

- Total of 27 individual configurations could be directly compared to data generated by SEA

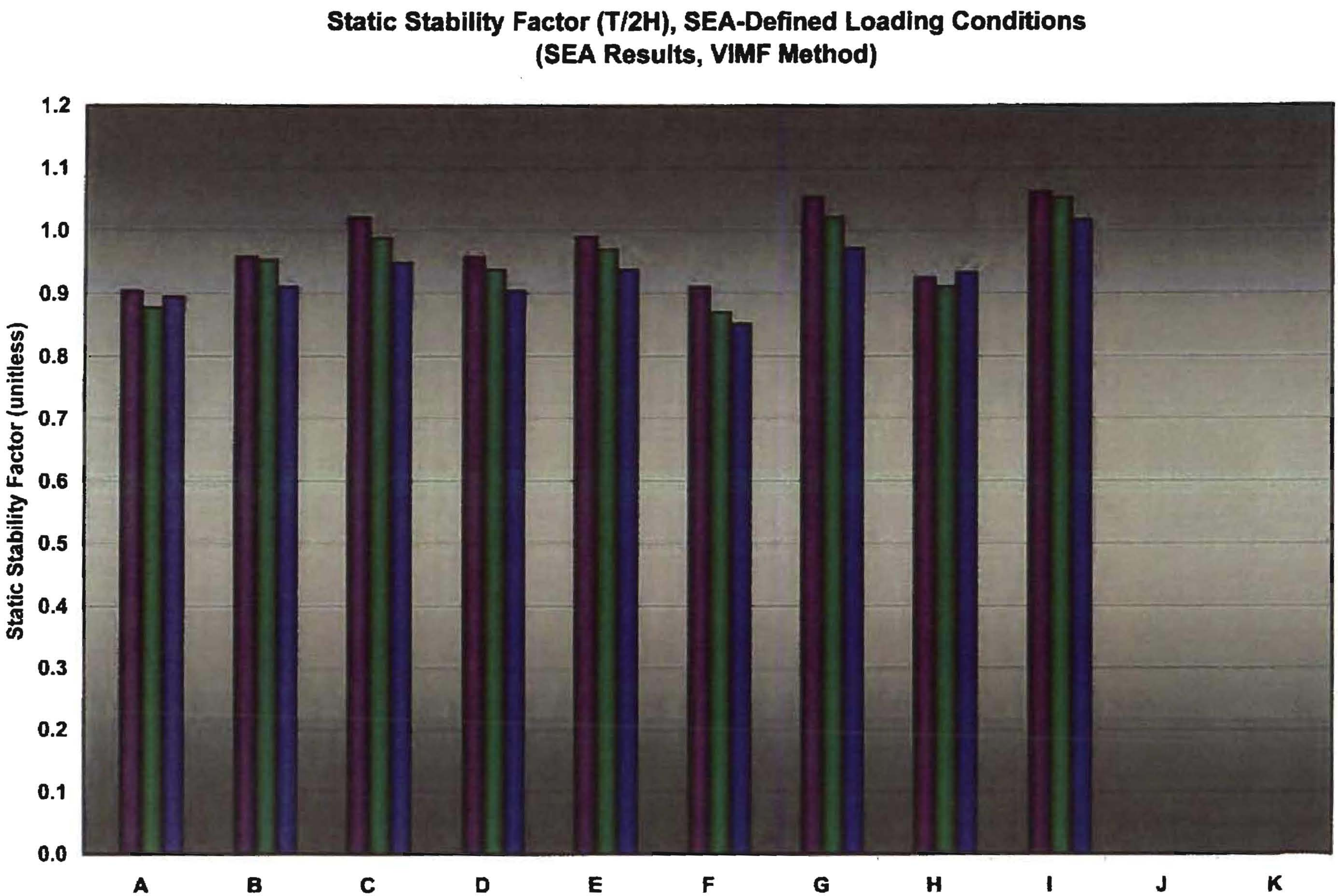
Why Not K_{st}?

...within a value of 0.01...

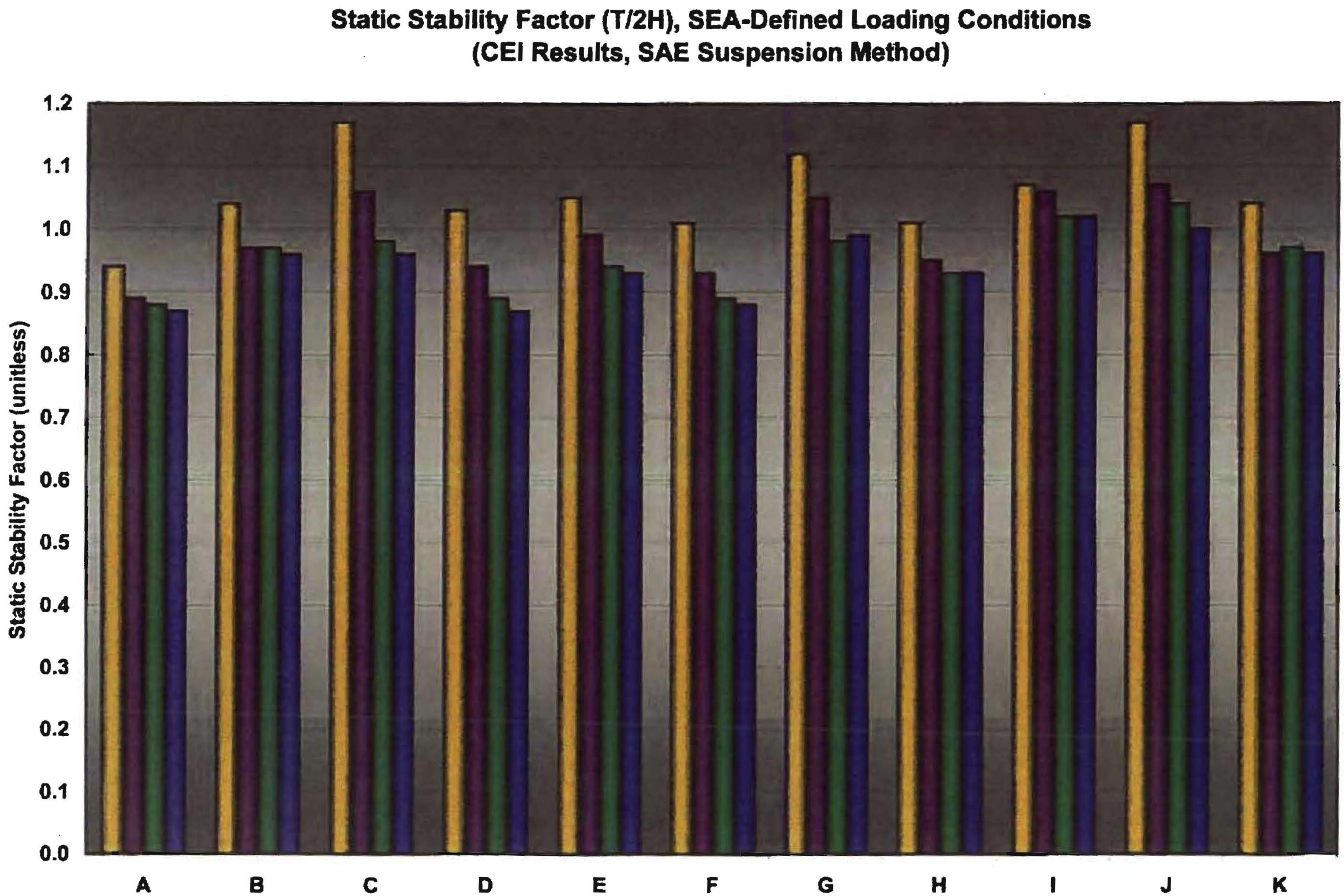
Values for the rollover resistance metric CSV are shown on Page 14. For the Operator and Passenger configurations, the CSV values are higher for the outrigger configurations, primarily because the vehicle roll inertias are higher with outriggers.

TTR results for the driver's side leading tilts, the passenger's side leading tilts, and the average of these two are contained on Pages 15, 16, and 17. For a given vehicle, among the loading configurations the average TTR is generally inversely related to the CG height. Charts comparing driver's side, passenger's side, and average TTR values for the Operator and Passenger configurations are contained on Page 18 and for the Operator, Instrumentation, and Outriggers configurations on Page 19. In general, the variations between the driver's side and passenger's side TTR values are related to the lateral offset of the CG positions for each vehicle and loading configuration. The measured TTR's are generally higher in the direction of tilt opposite of the direction of the lateral offset in CG position. Charts comparing TTA values for the same two loading configurations as Pages 18 and 19 are given on Pages 20 and 21.

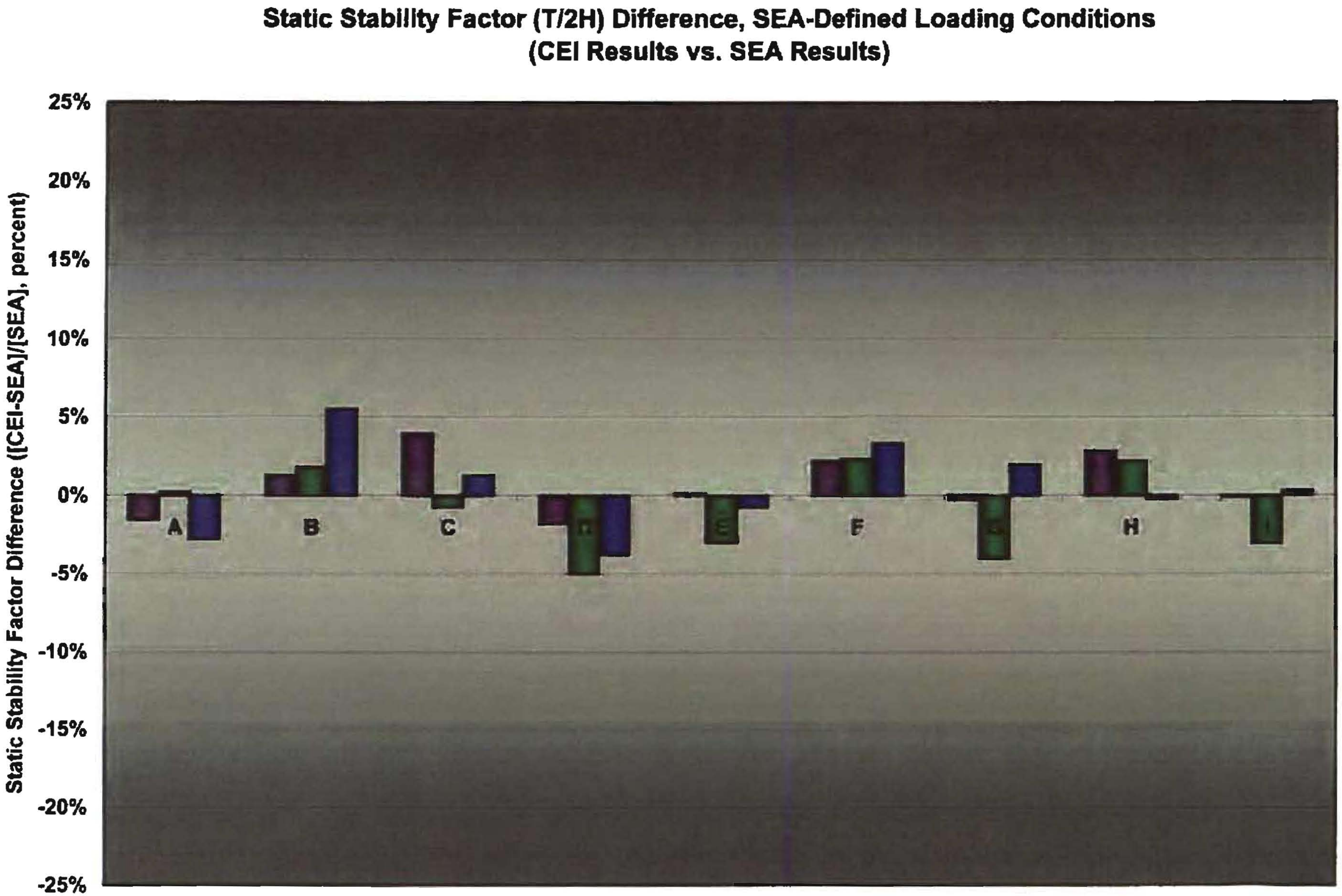
SSF Results


Static Stability Factor (T/2H), SEA-Defined Loading Conditions
(SEA Results, VIMF Method)
Static Stability Factor (unitless)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
A
B
C
D
E
F
G
H
I
J
K

SSF Results


Static Stability Factor (T/2H), SEA-Defined Loading Conditions
(CEI Results, SAE Suspension Method)
Static Stability Factor (unitless)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
A
B
C
D
E
F
G
H
I
J
K

SSF Results


Static Stability Factor (T/2H) Difference, SEA-Defined Loading Conditions
(CEI Results vs. SEA Results)
Static Stability Factor Difference ([CEI-SEA]/[SEA], percent)
25%
20%
15%
10%
5%
0%
-5%
-10%
-15%
-20%
-25%
A
B
C
F
H

SSF Results

- Maximum difference of ~5% compared to SEA data
- Average difference of ~2% compared to SEA data
- Generally consistent results independent of testing methodology that satisfy CPSC/SEA-stated objective of being both accurate and repeatable
- Generally relates to a machine's crash avoidance capacity
- Any proposed standard or metric would need to consider test-to-test variability

Tilt Table

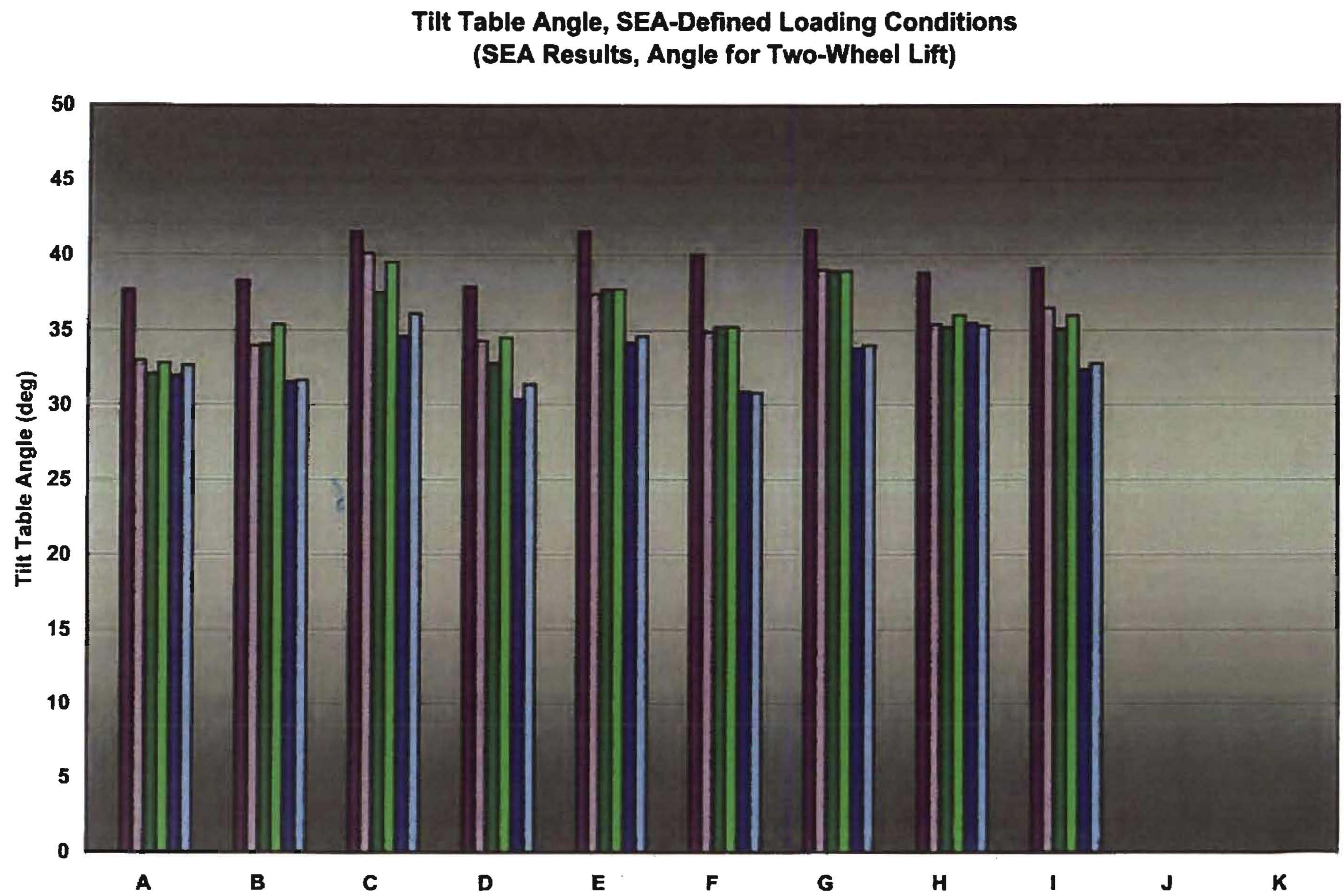
Tilt Table Evaluation

- Measurement of minimum TTA required for two-wheel lift (TWL) on tilt table apparatus

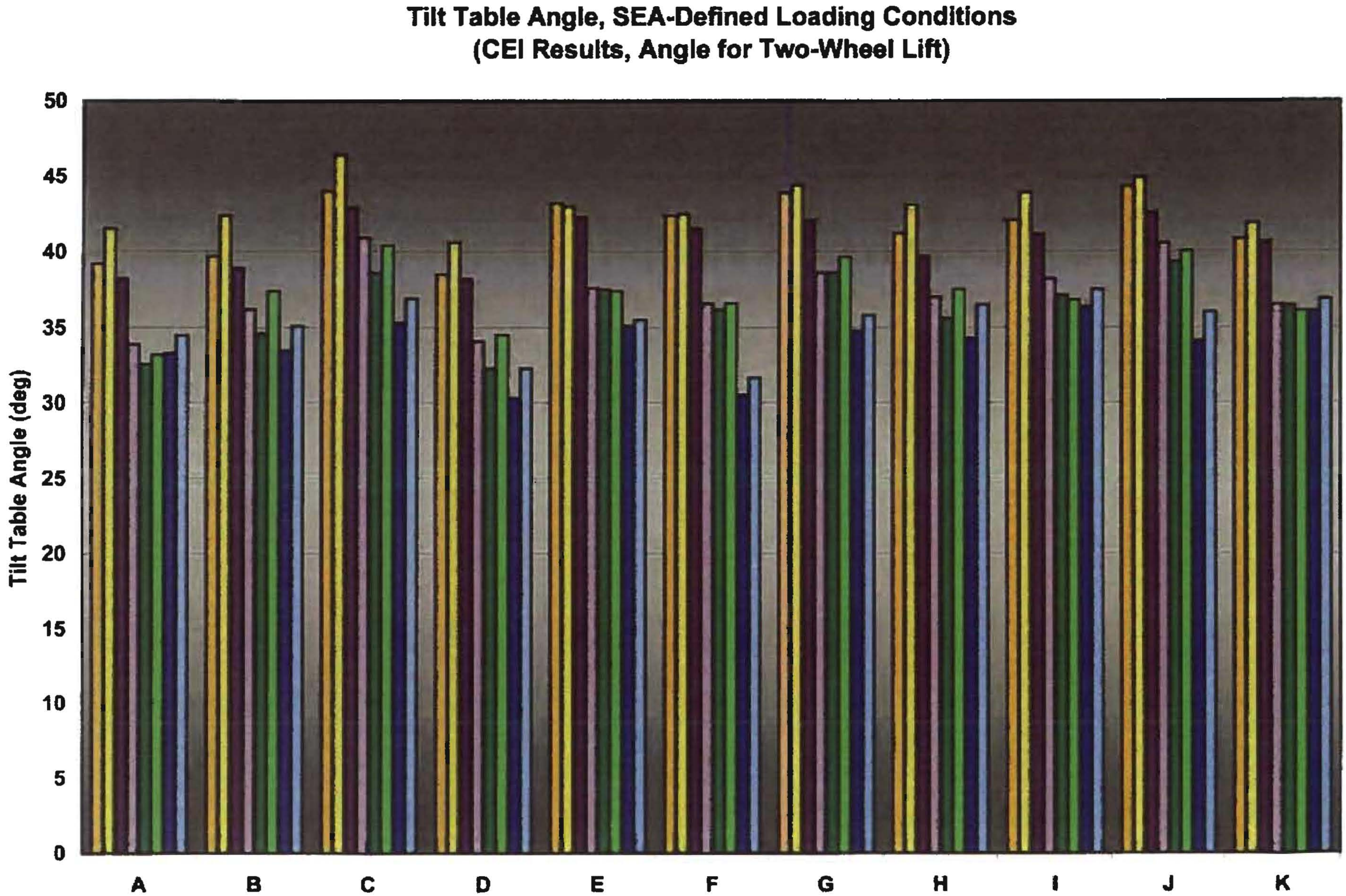
- Total of 88 individual configurations evaluated
  - ✓Eleven machines
  - ✓Four loading configurations
  - ✓Two orientations

- Total of 54 individual configurations could be directly compared to data generated by SEA

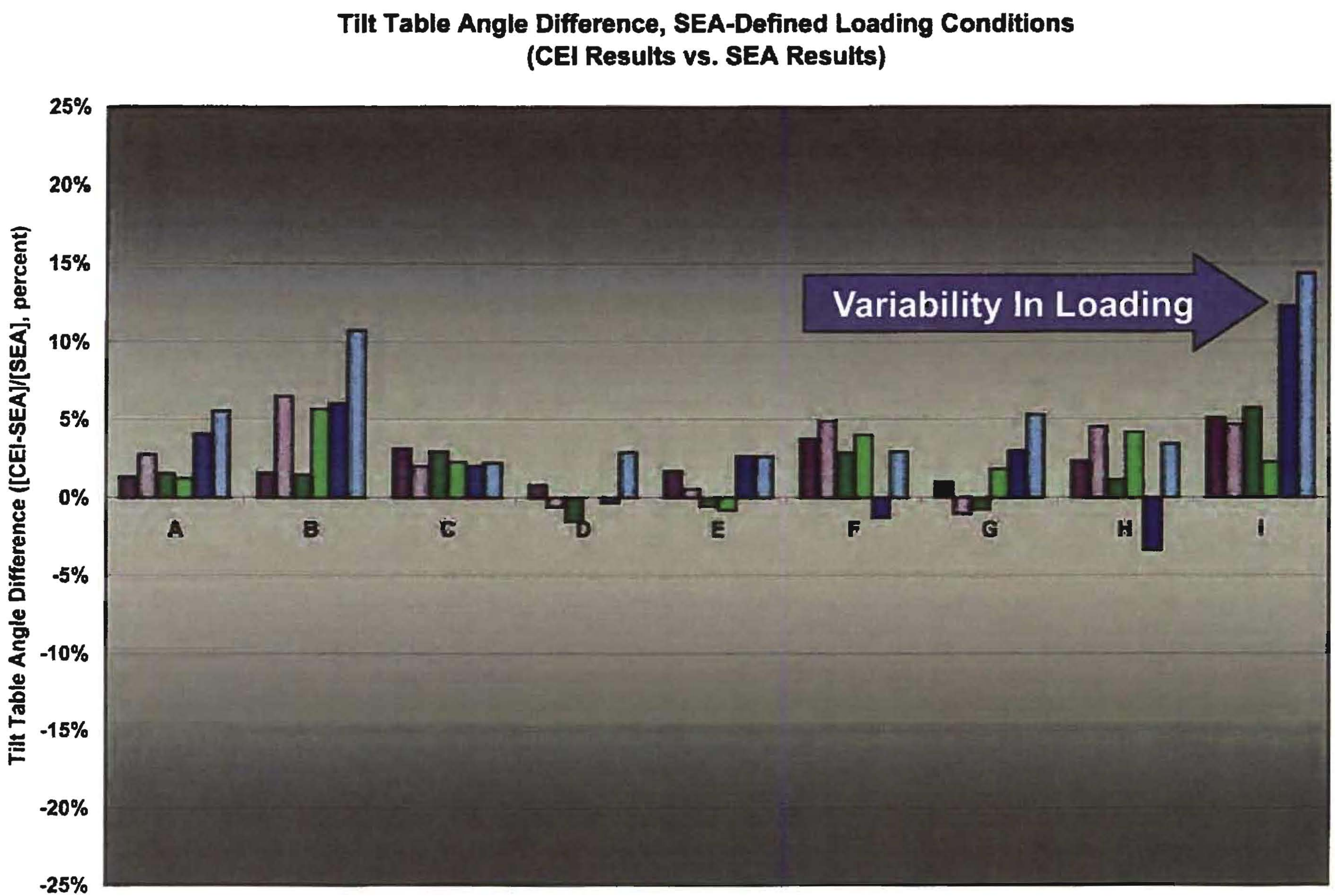
Tilt Table Results



Tilt Table Results



Tilt Table Results



Tilt Table Results

- Maximum difference of ~14% compared to SEA data
- Average difference of ~3% compared to SEA data
- Generally consistent results independent of testing methodology that satisfy CPSC/SEA-stated objective of being both accurate and repeatable
- Generally relates to a machine's crash avoidance capacity
- Any proposed standard or metric would need to consider test-to-test variability

Drop-Throttle J-Turn Steering Wheel Angle

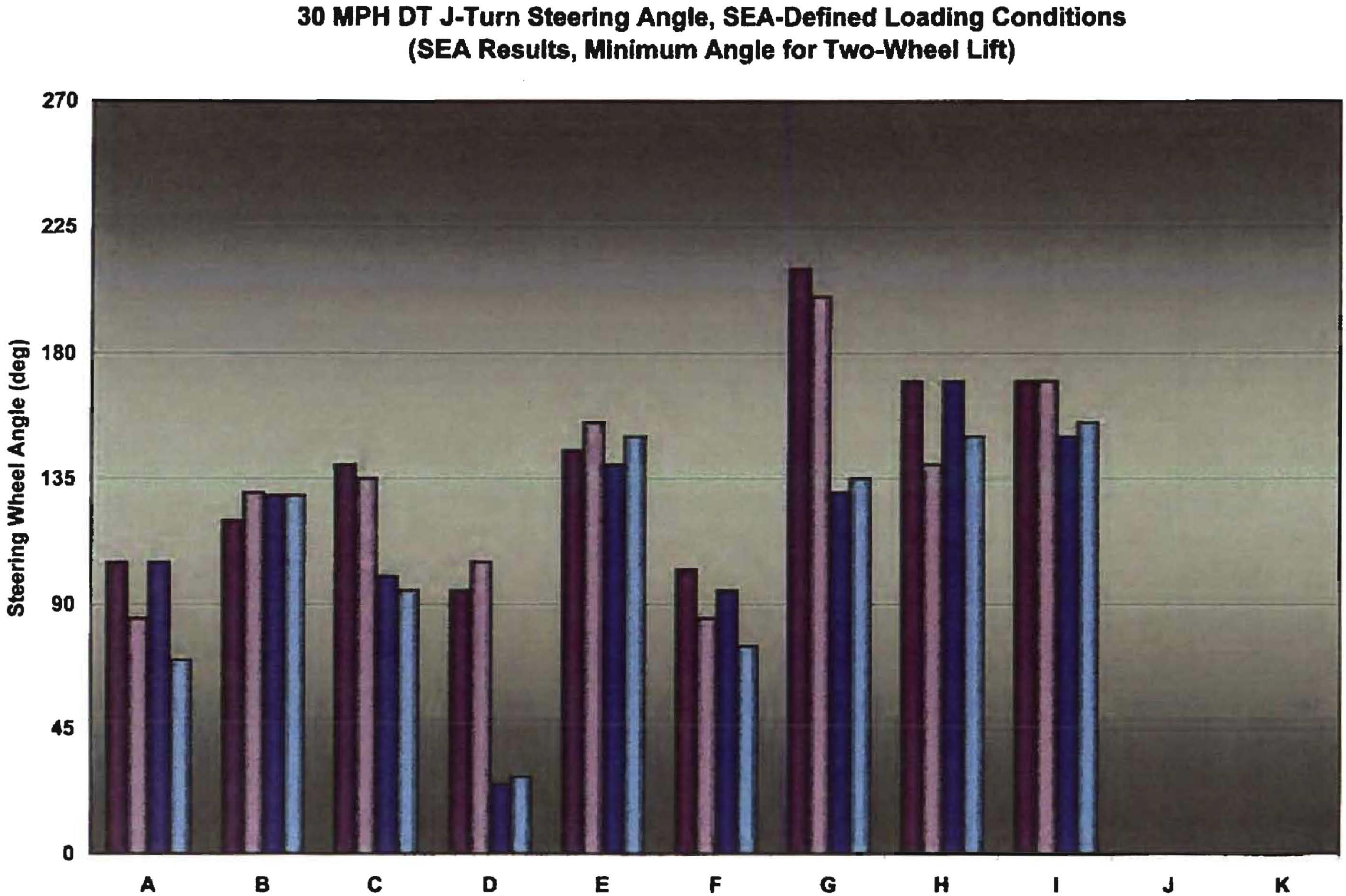
J-Turn SWA Evaluation

- Determination of minimum SWA required for outrigger contact during aggressive dropped-throttle J-Turn (500°/s @ 30mph) on concrete surface

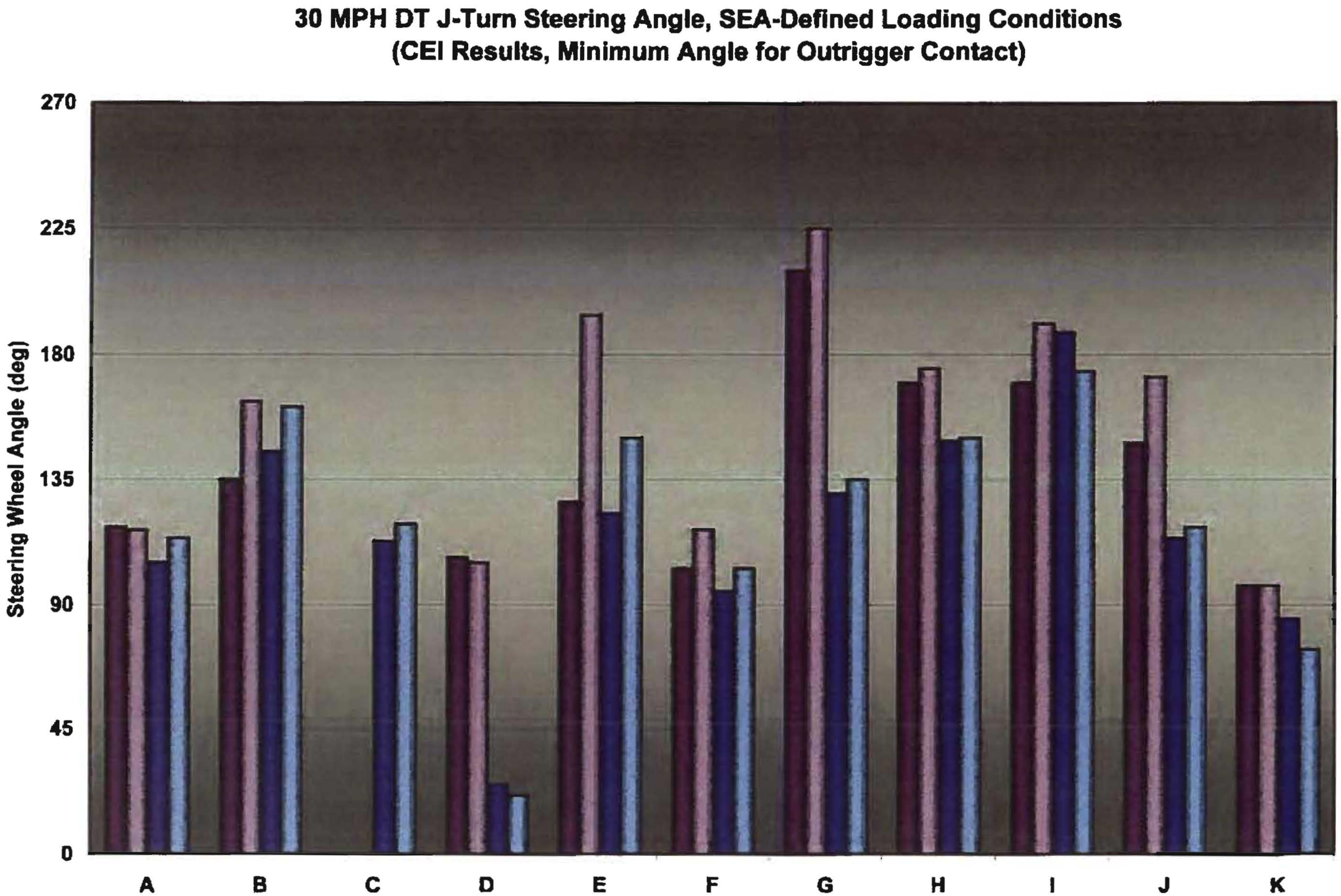
- Total of 44 individual configurations evaluated
  - ✓Eleven machines (A through K)
  - ✓Two loading configurations (SEA-defined)
  - ✓Two directions (left and right)

- Total of 36 individual configurations could be directly compared to data generated by SEA

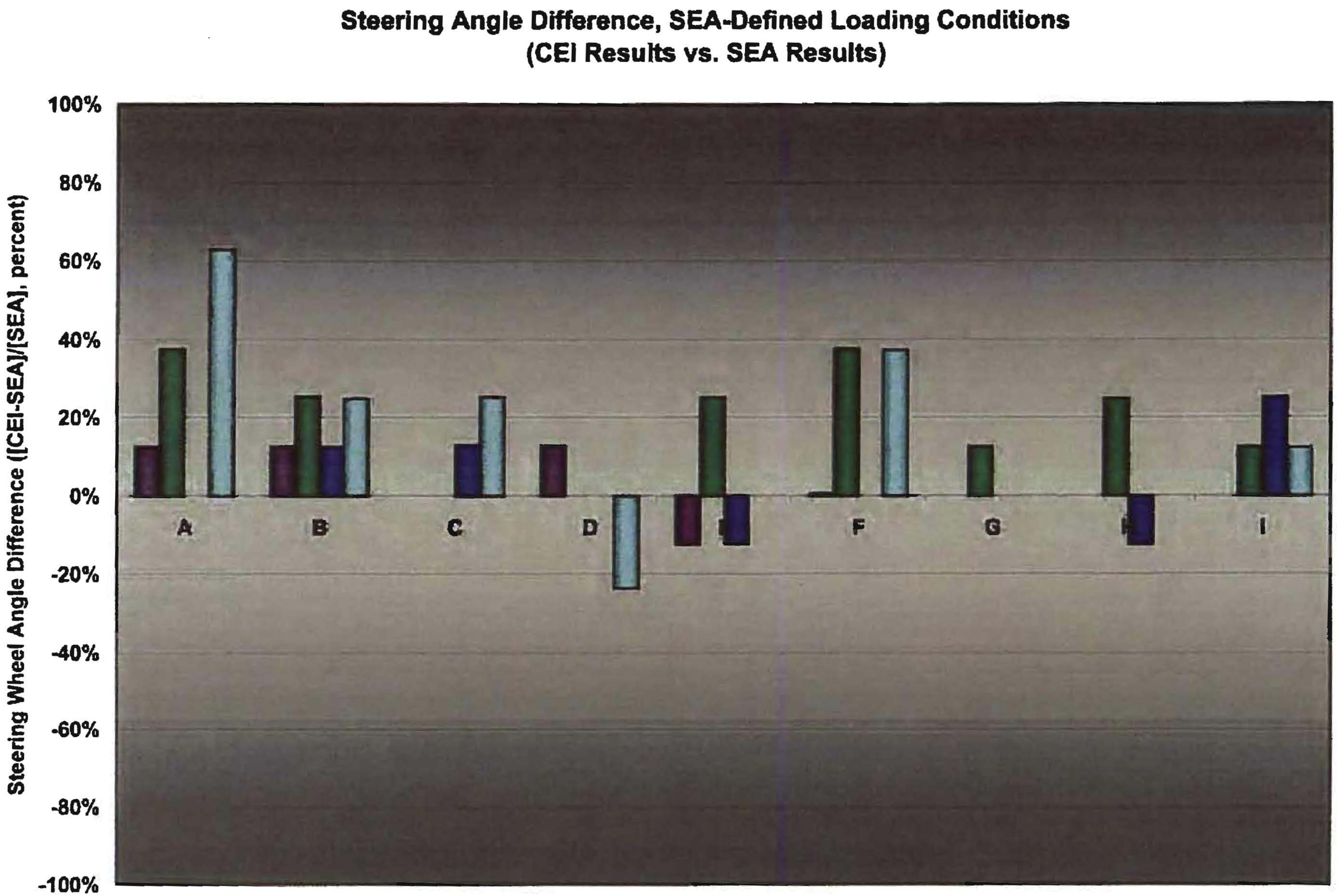
J-Turn SWA Results



J-Turn SWA Results



J-Turn SWA Results

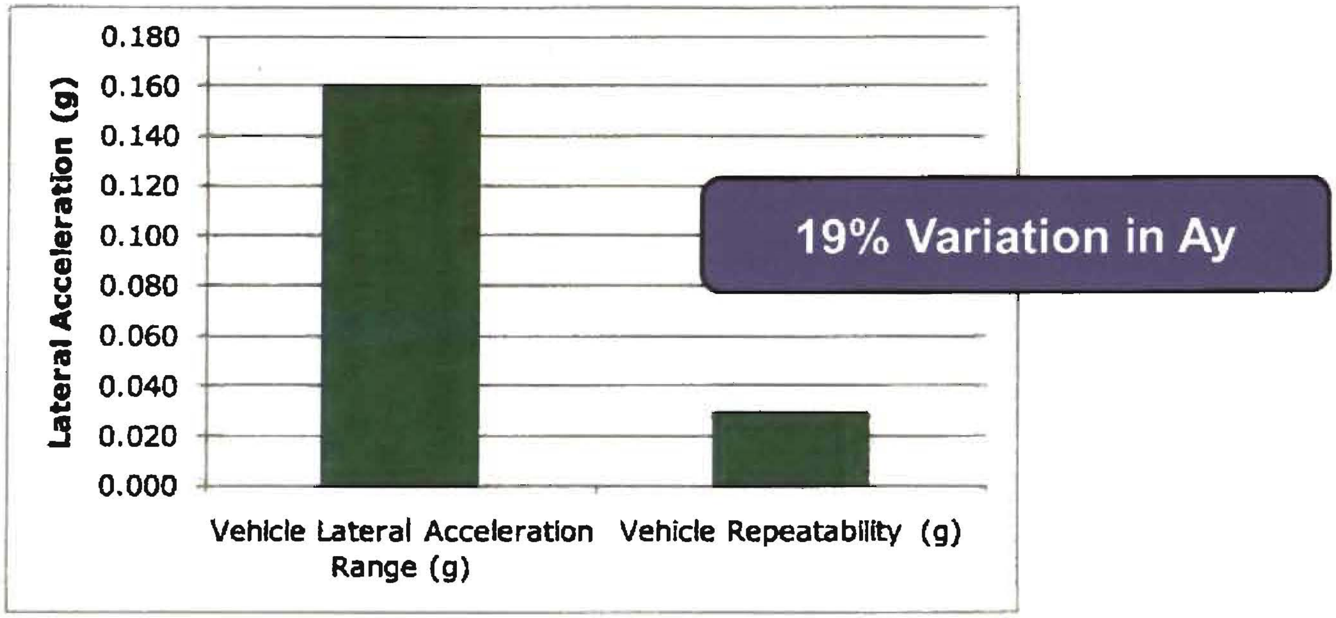


J-Turn SWA Results

- Maximum difference of ~63% compared to SEA data
- Average difference of ~14% compared to SEA data
- Inconsistent results based on specific testing conditions and methodology that do not satisfy the CPSC/SEA-stated objective of being both accurate and repeatable
- Inappropriate for use as a standard or metric due to large test-to-test variability

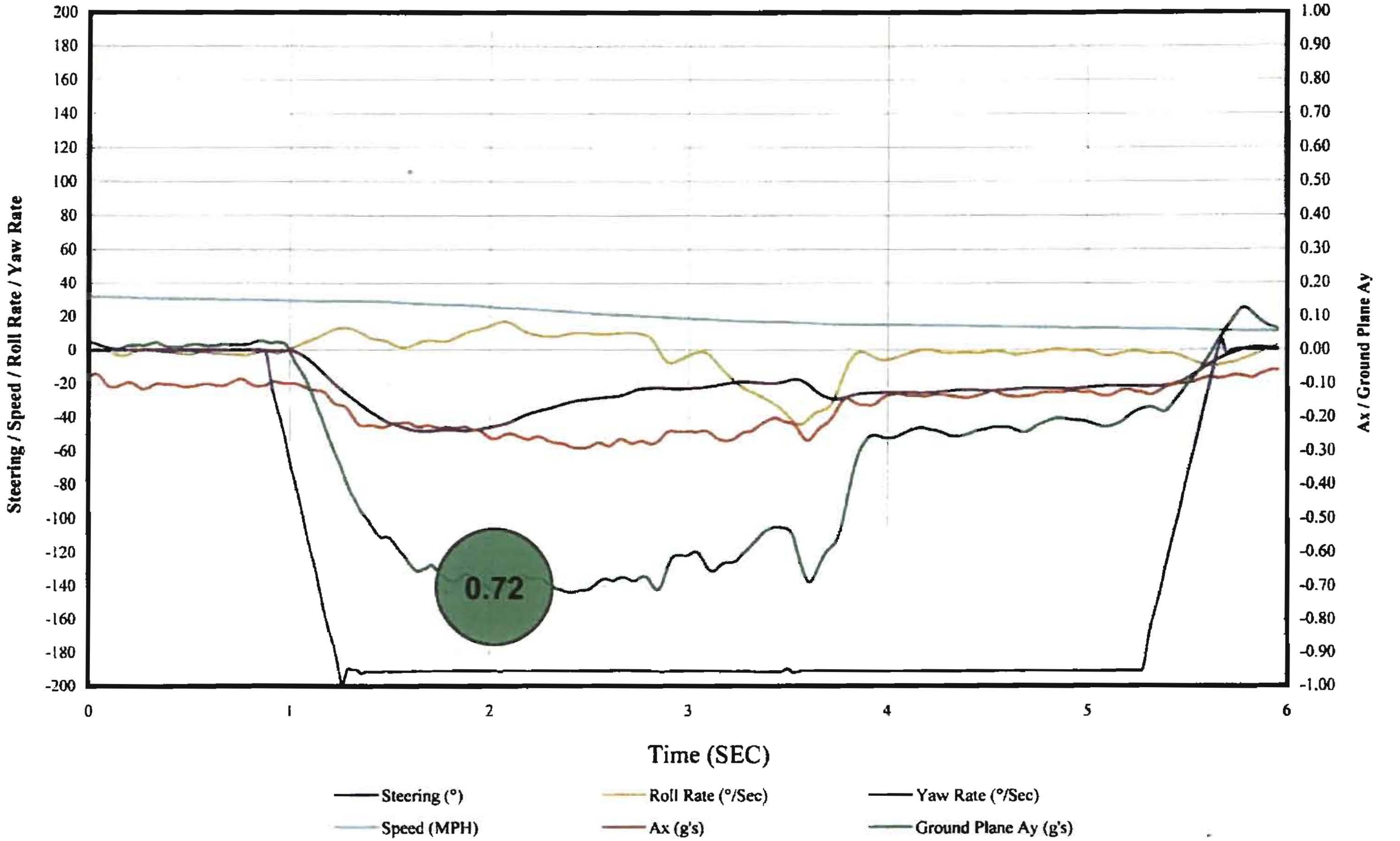
Drop-Throttle J-Turn
Ay Test Variability

OPEI Analysis of SEA Data

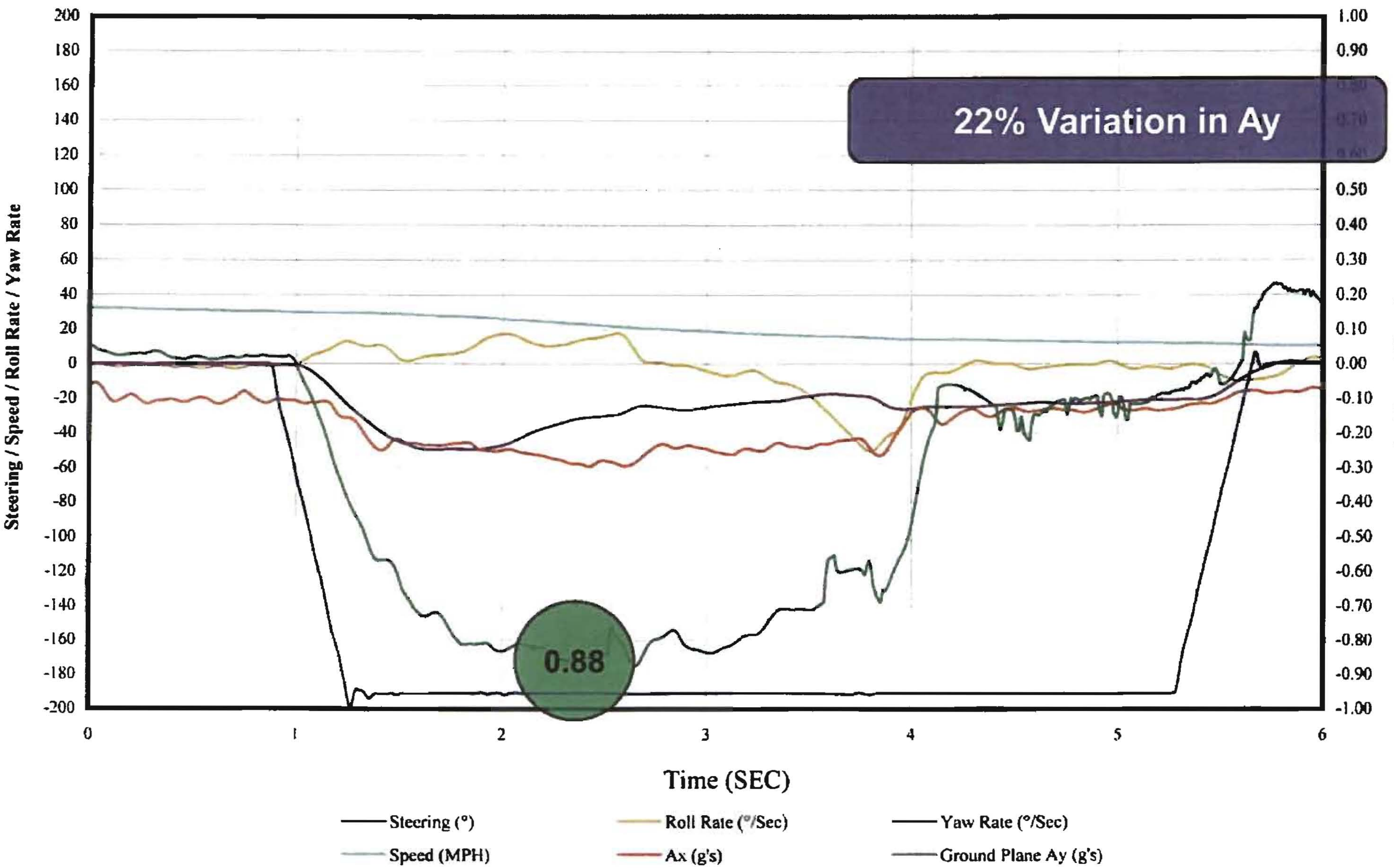


The testing showed that there is a 0.03 range of acceleration values when measuring one vehicle with a common instrumentation set-up. This accounts for 19% of the total range of lateral acceleration at two wheel lift of the 11 vehicles measured by the CPSC. This variation is from a test using the same vehicle with as many of the previously mentioned variables controlled as possible. If other variables are included the variation would conceivably be higher than 19%.

J-Turn Ay Variability / CEI Analysis



J-Turn Ay Variability / CEI Analysis



J-Turn Ay Variability

- OPEI calculated vehicle variation of ~19% of data range using SEA results
- CEI measured ~22% Ay test-to-test variation
- The NHTSA does not employ any form of a J-Turn test protocol for either consumer advisory or regulatory purposes
- The NHTSA does not employ any form of a lateral acceleration requirement for either consumer advisory or regulatory purposes

J-Turn Ay Variability

- Inconsistent results based on specific testing conditions and methodology that do not satisfy the CPSC/SEA-stated objective of being both accurate and repeatable

- Inappropriate for use as a standard or metric due to large test-to-test variability

Drop-Throttle J-Turn
Minimum Ay

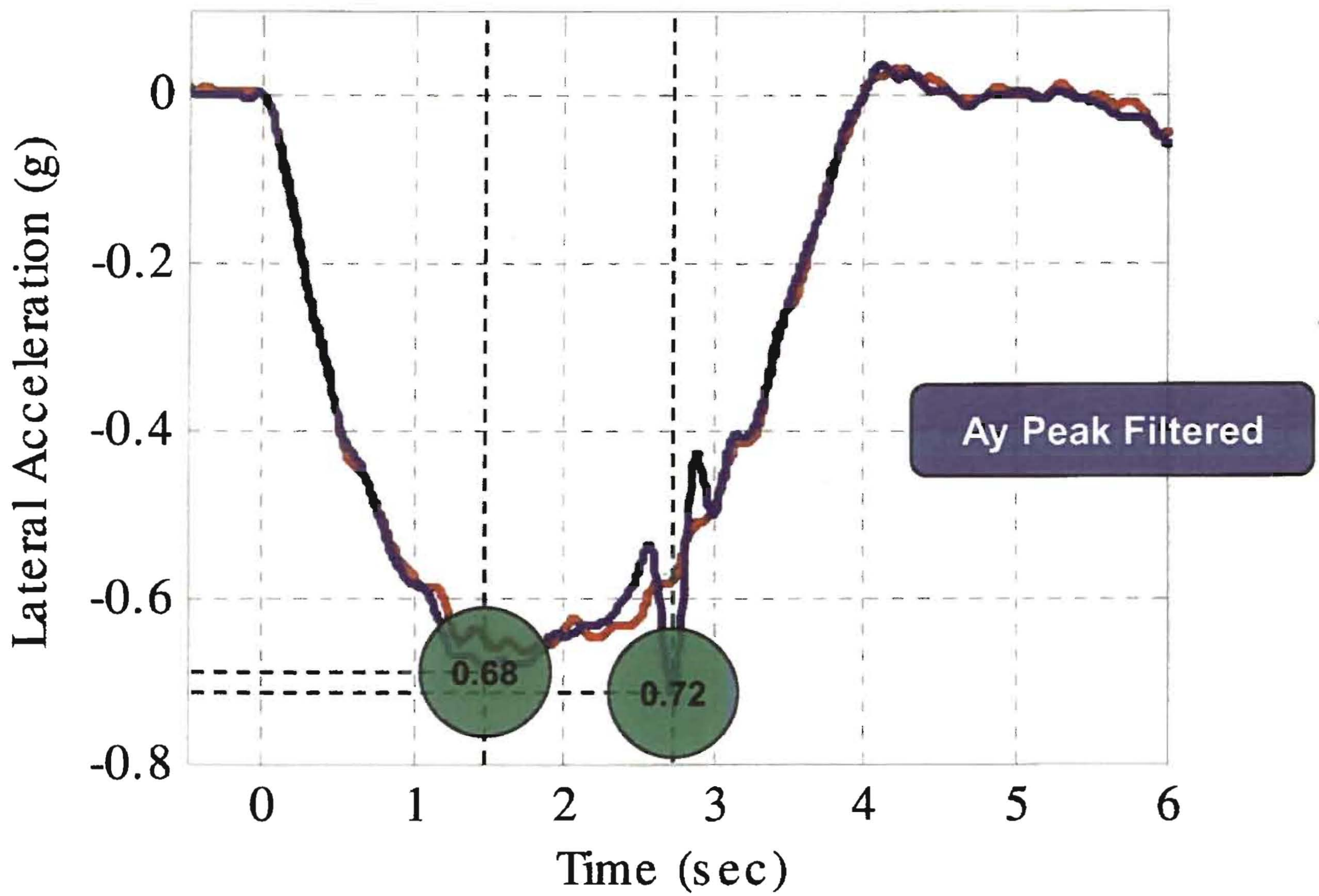
J-Turn Ay Evaluation

- Determination of minimum Ay required for outrigger contact during aggressive dropped-throttle J-Turn (500°/s @ 30mph) on concrete surface

- Total of 44 individual configurations evaluated
  - ✓Eleven machines (A through K)
  - ✓Two loading configurations (SEA-defined)
  - ✓Two directions (left and right)

- Total of 36 individual configurations could be directly compared to data generated by SEA

SEA J-Turn Ay Results / Vehicle G



J-Turn Ay Measurement

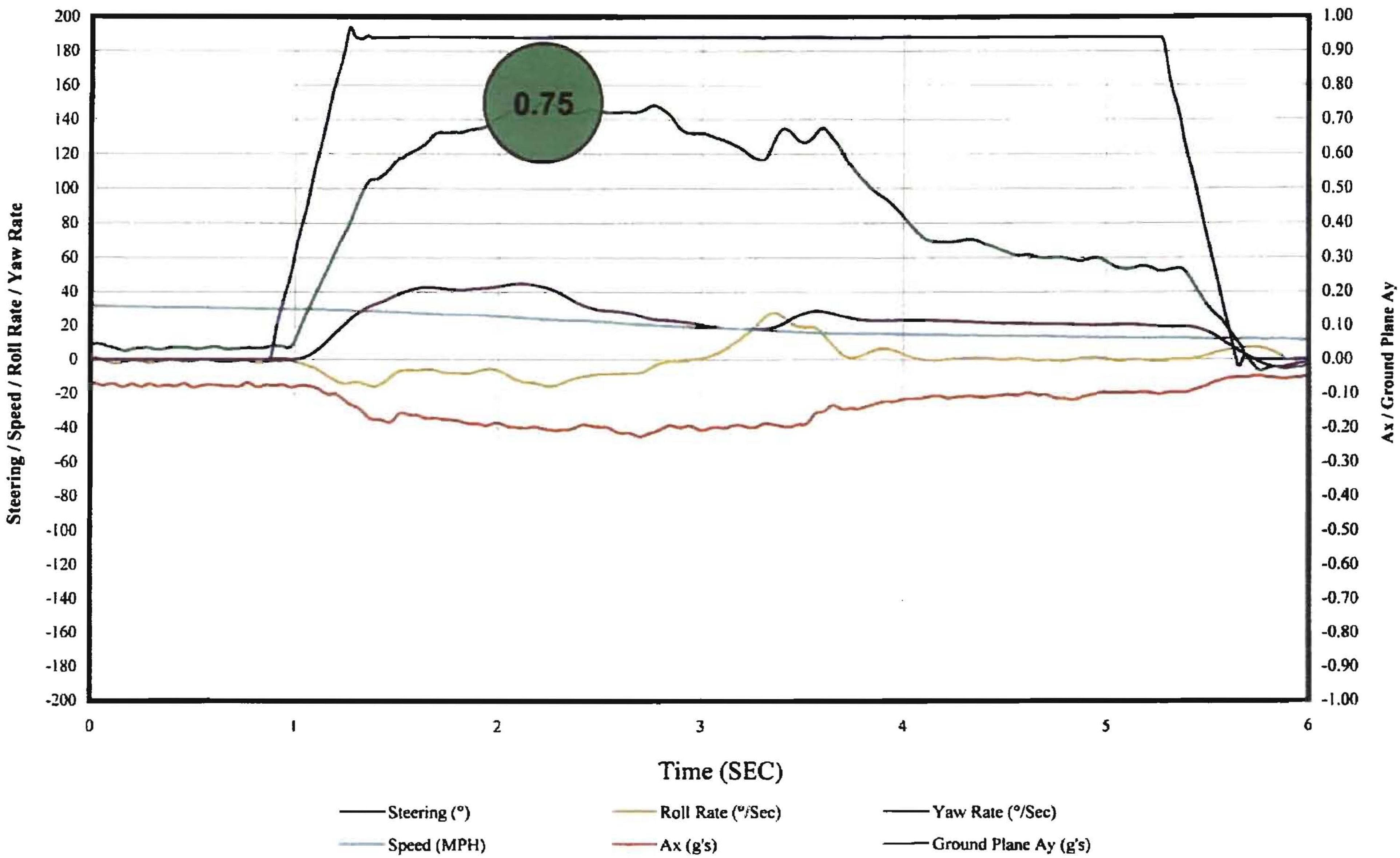
- Results generated by CEI (using SEA methodology) show a wider range of rolling motions

- Some vehicles displayed rolling motions which prevented an accurate or reliable measurement of Ay

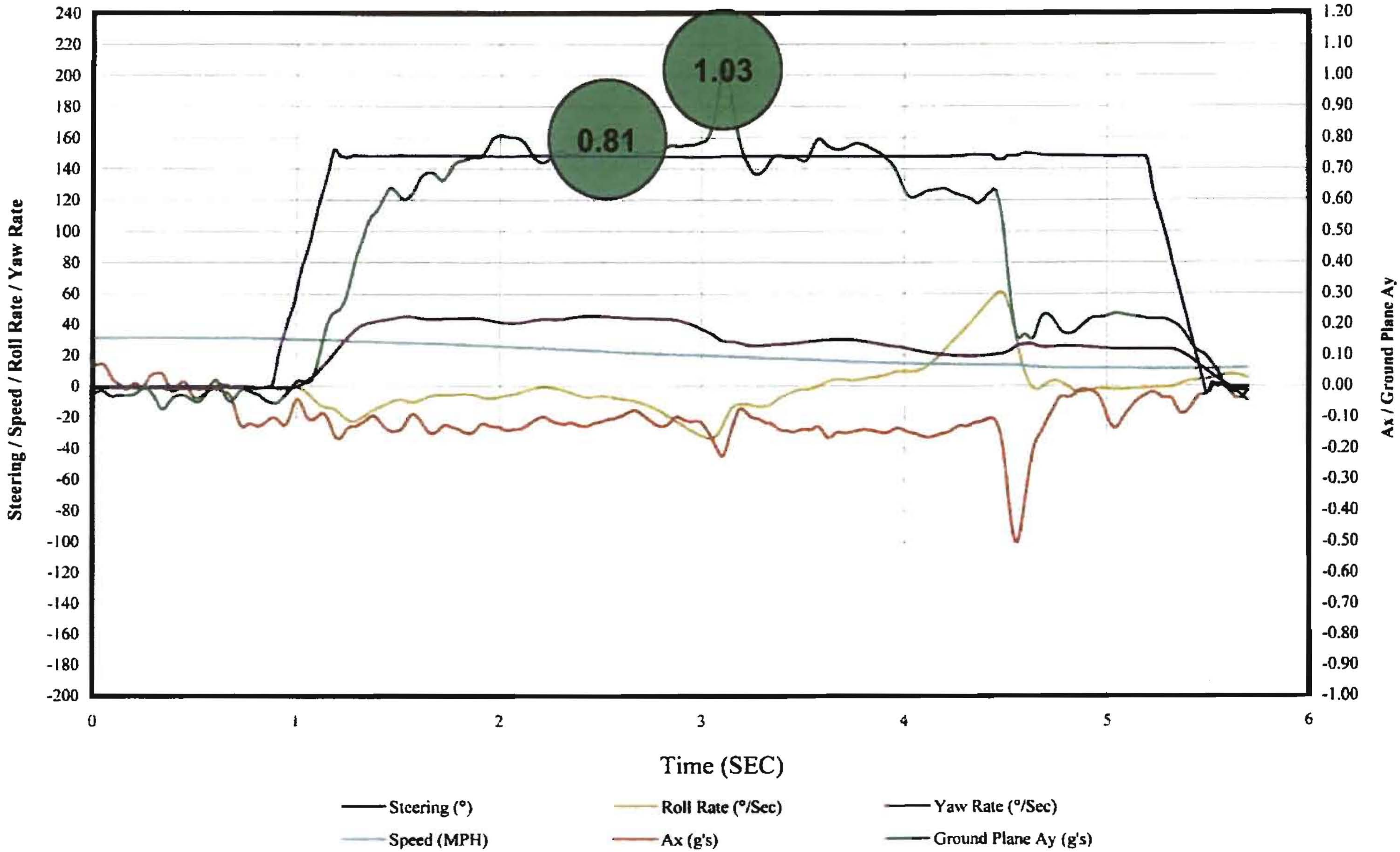
- Ay selected by CEI as local maximum excluding transients generated

- Like SEA, unknown / unquantified effect of outrigger contact during generation of local maximum

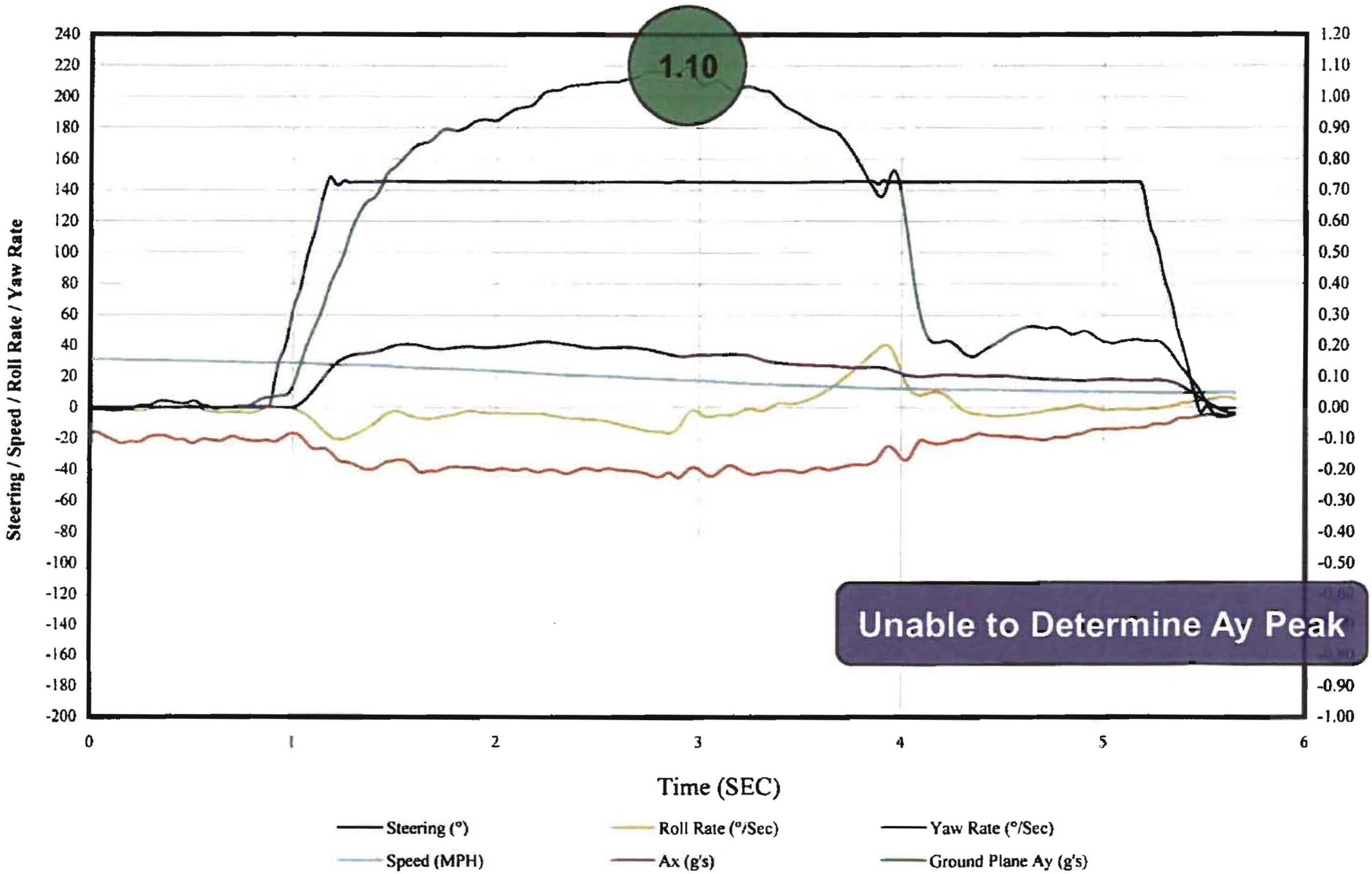
J-Turn Ay Results / Vehicle I



J-Turn Ay Results / Vehicle J

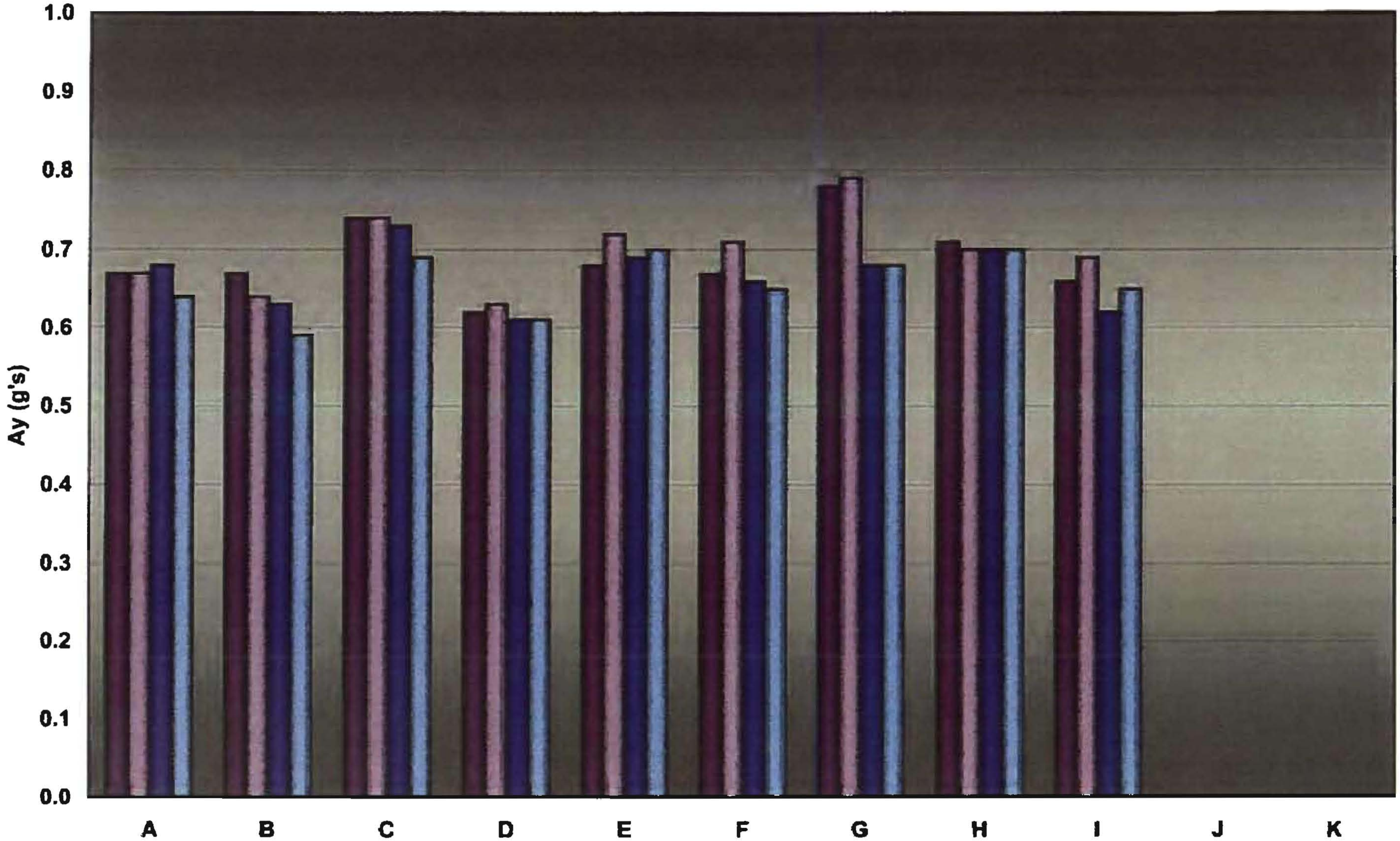


J-Turn Ay Results / Vehicle B

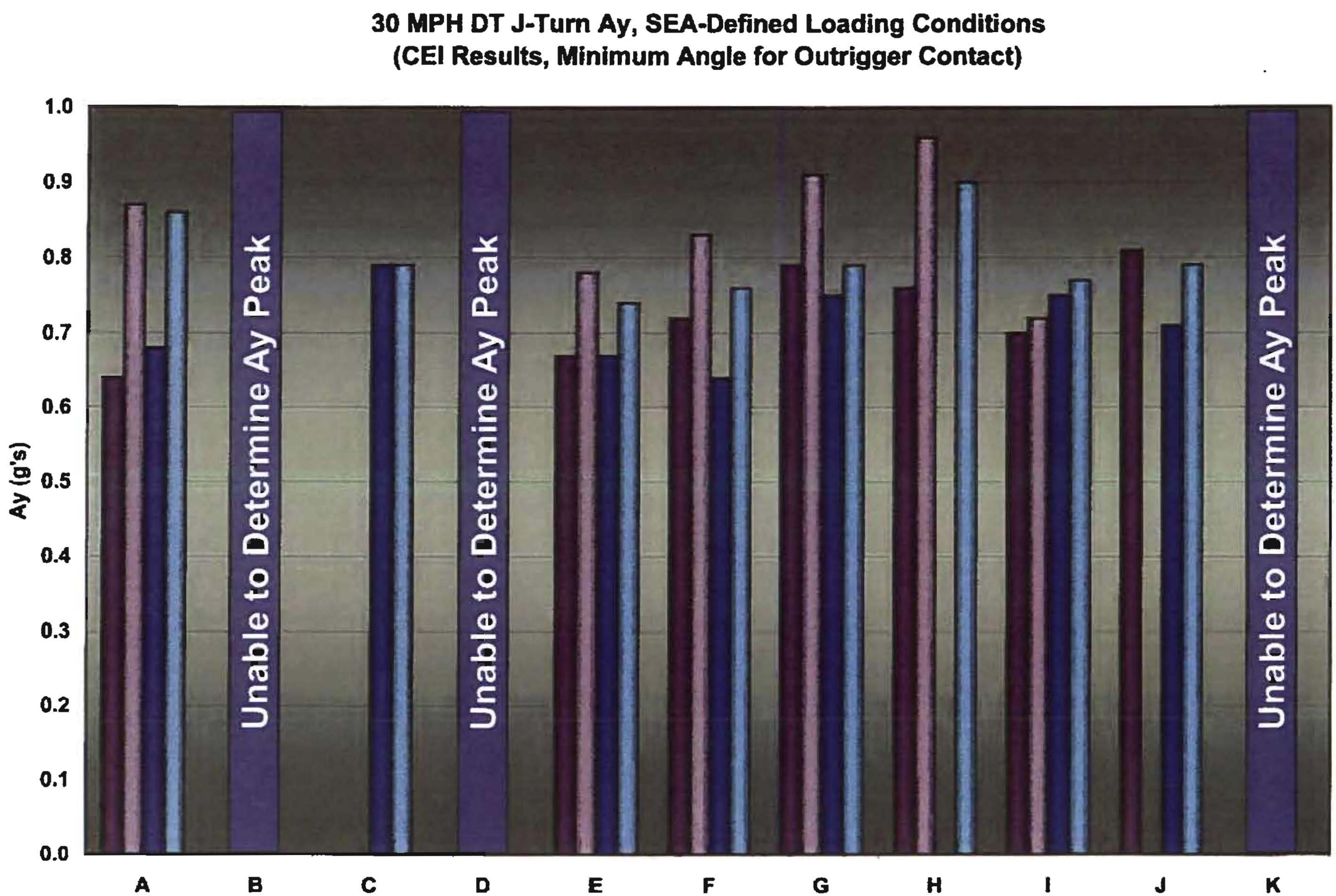


J-Turn Ay Results

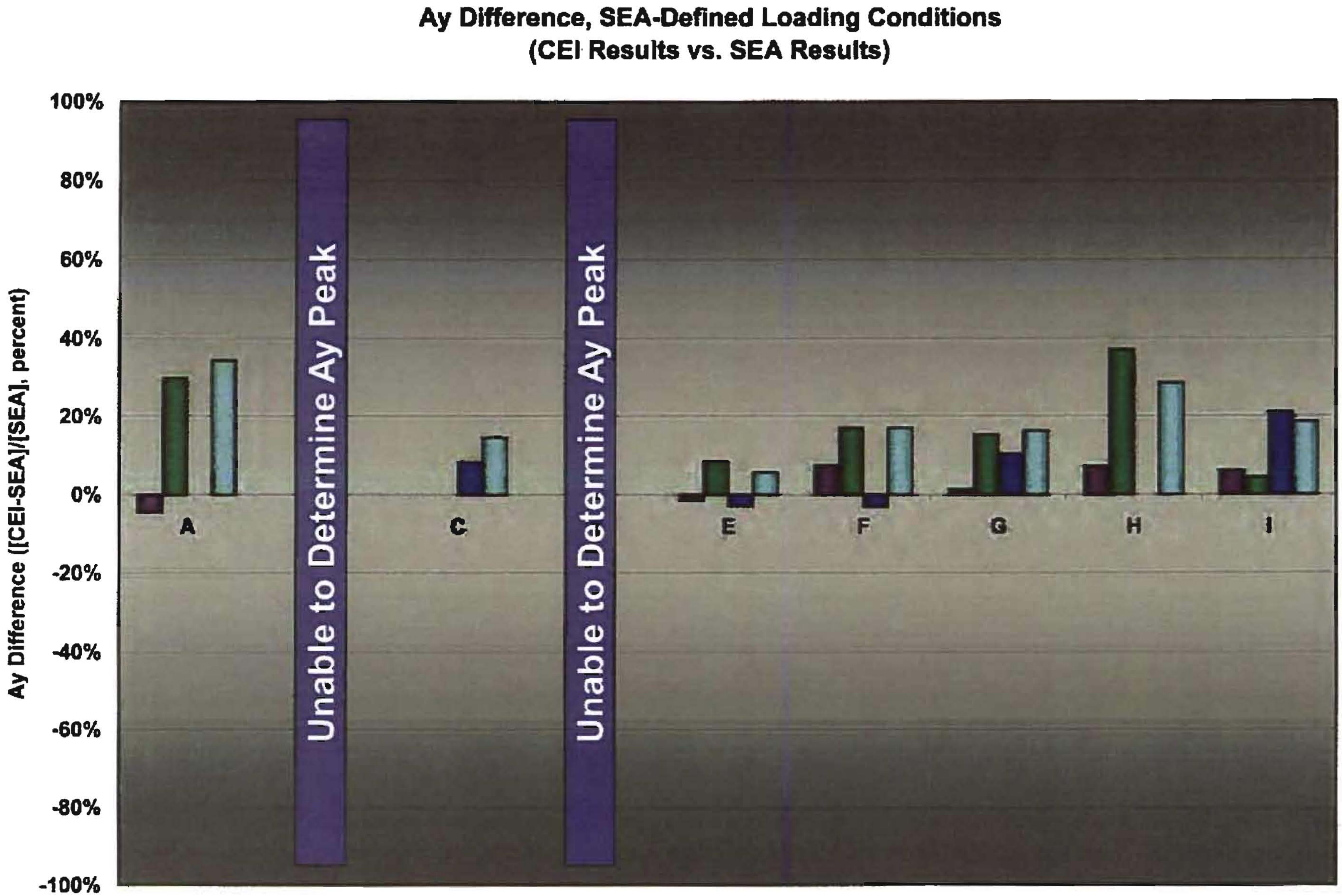
30 MPH DT J-Turn Ay, SEA-Defined Loading Conditions
(SEA Results, Minimum Angle for Two-Wheel Lift)



J-Turn Ay Results



J-Turn Ay Results



J-Turn Ay Results

- Maximum difference of ~37% compared to SEA data
- Average difference of ~13% compared to SEA data
- Inconsistent results based on specific testing conditions and methodology that do not satisfy the CPSC/SEA-stated objective of being both accurate and repeatable
- Inappropriate for use as a standard or metric due to large test-to-test variability

On-Highway Steering Characterization

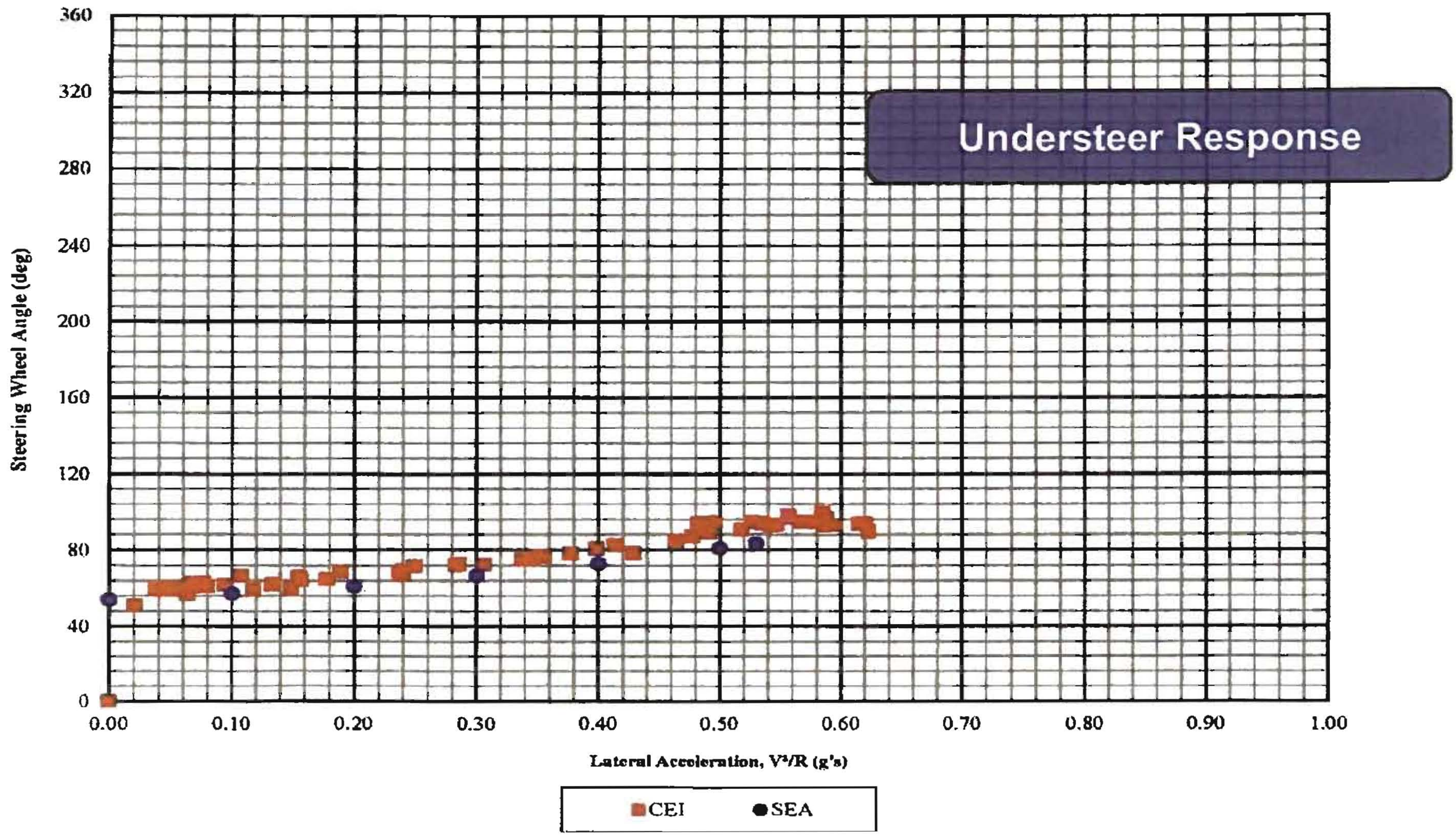
On-Highway Steering Results

- Measurement of SWA as a function of vehicle lateral acceleration on concrete

- Total of 88 individual configurations evaluated
  - ✓Eleven machines (A through K)
  - ✓Two loading configurations (SEA-defined)
  - ✓Two orientations (CW and CCW)
  - ✓Two diameters (50’ radius and 100’ radius)

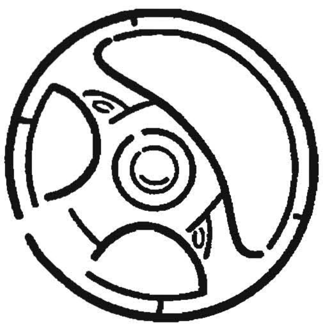
- Total of 36 individual configurations could be directly compared to data generated by SEA

On-Highway Steering / Vehicle C

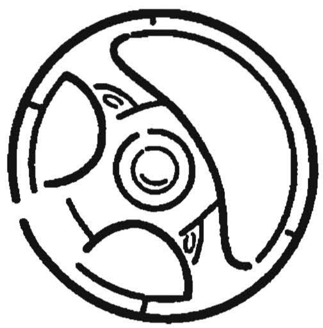


On-Highway Steering / Vehicle C

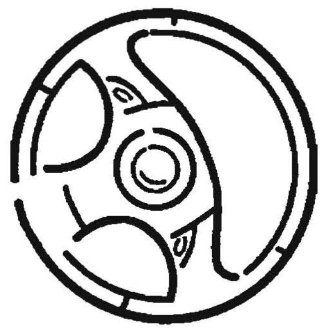
Two-Wheel Drive on Concrete – Understeer Response



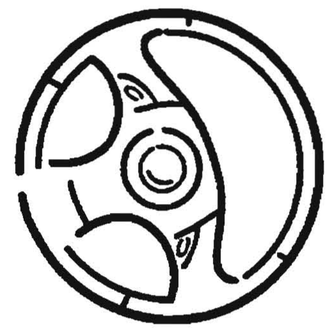
0.00 g



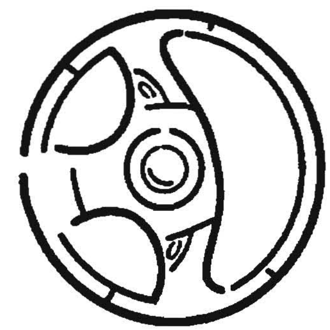
0.20 g



0.30 g

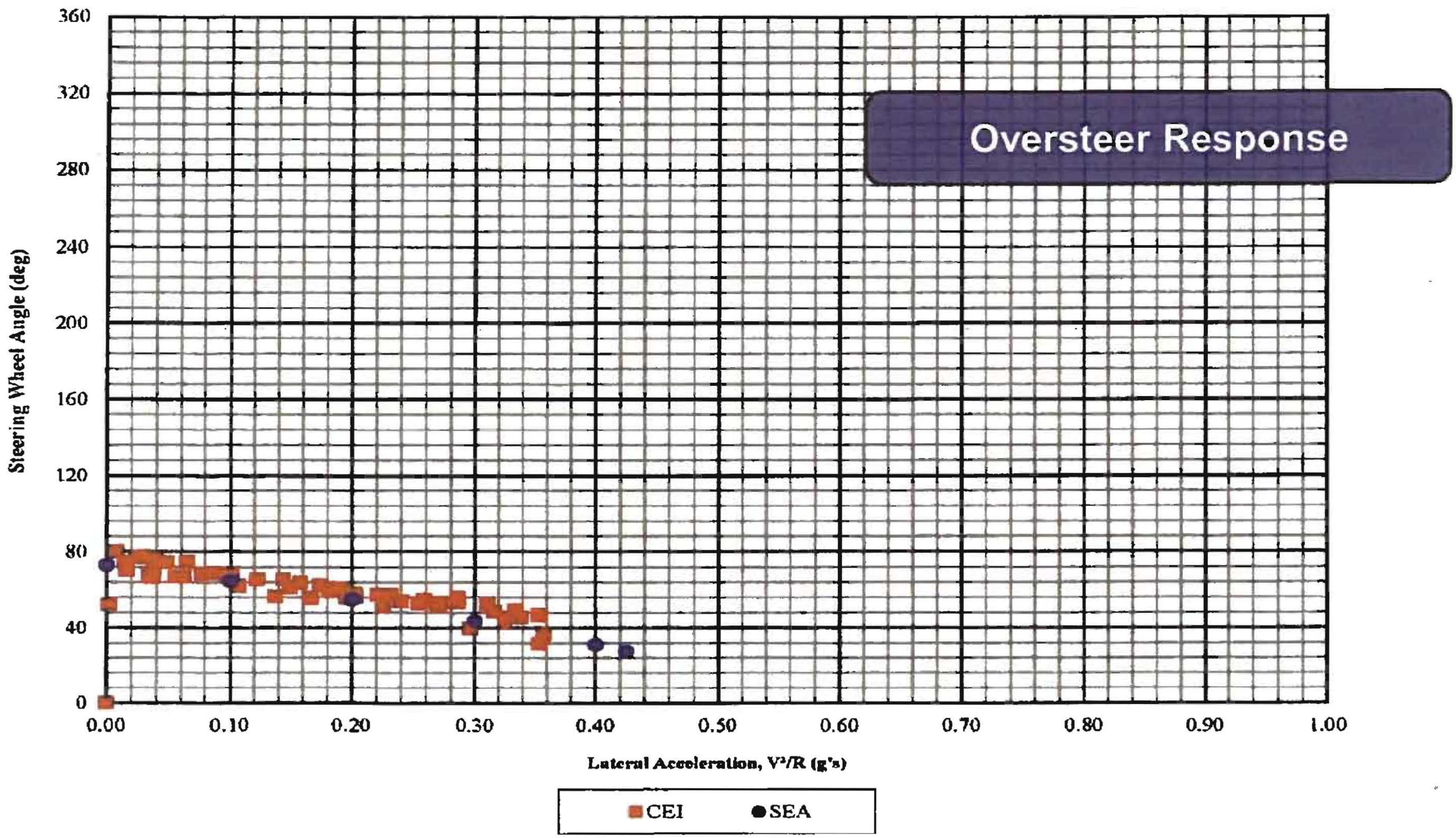


0.40 g



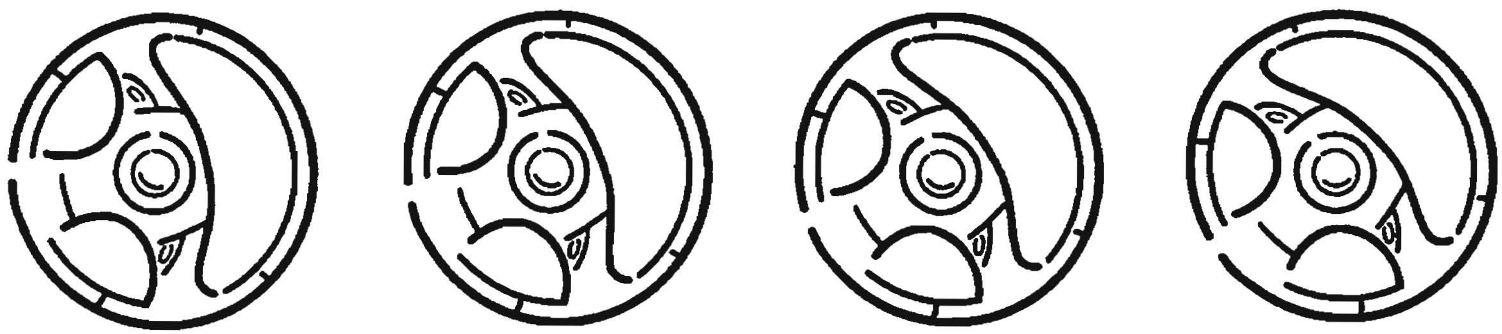
0.50 g

On-Highway Steering / Vehicle D



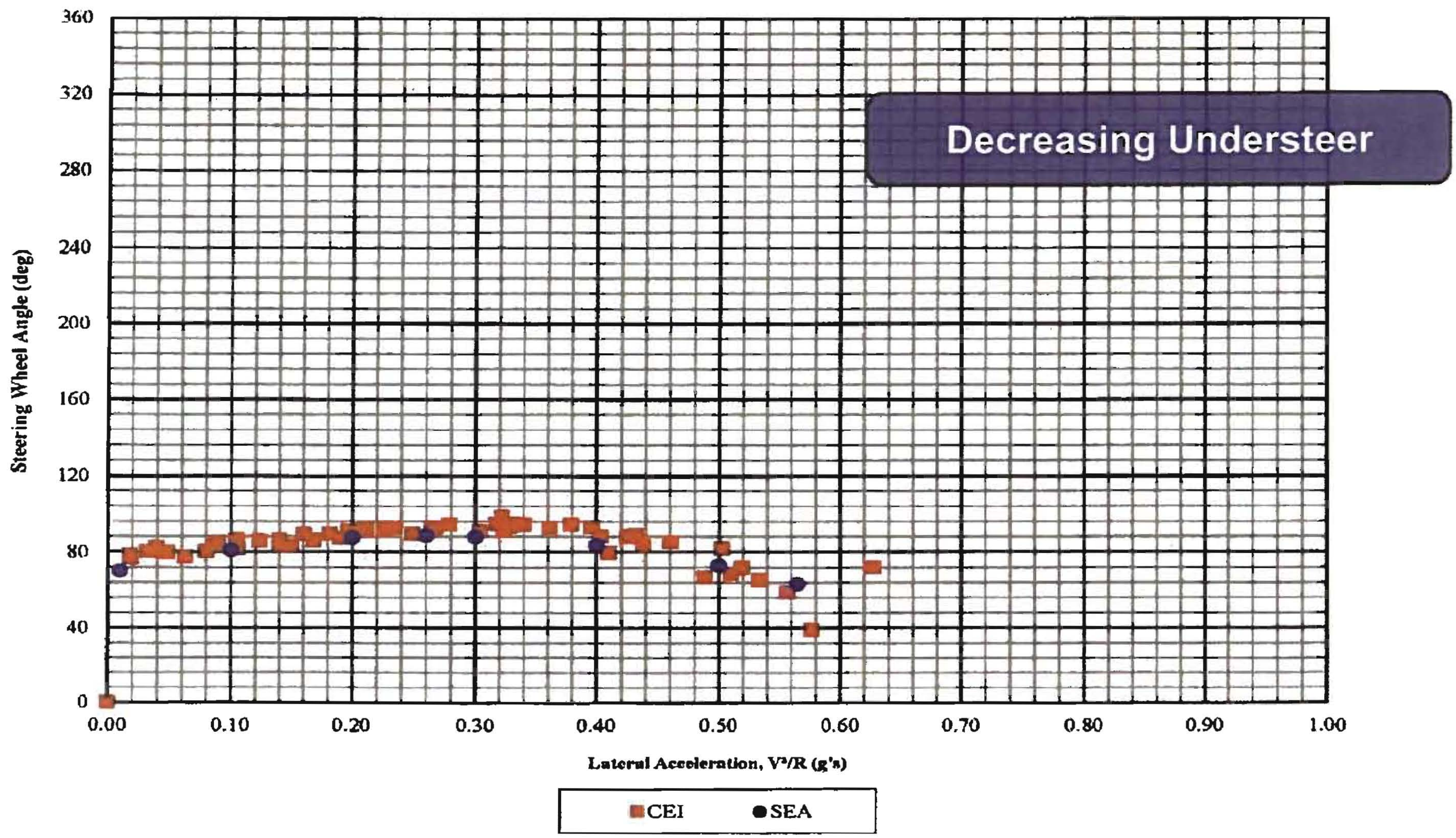
On-Highway Steering / Vehicle D

Two-Wheel Drive on Concrete – Oversteer Response



0.00 g	0.10 g	0.20 g	0.30 g	0.40 g
				N/A

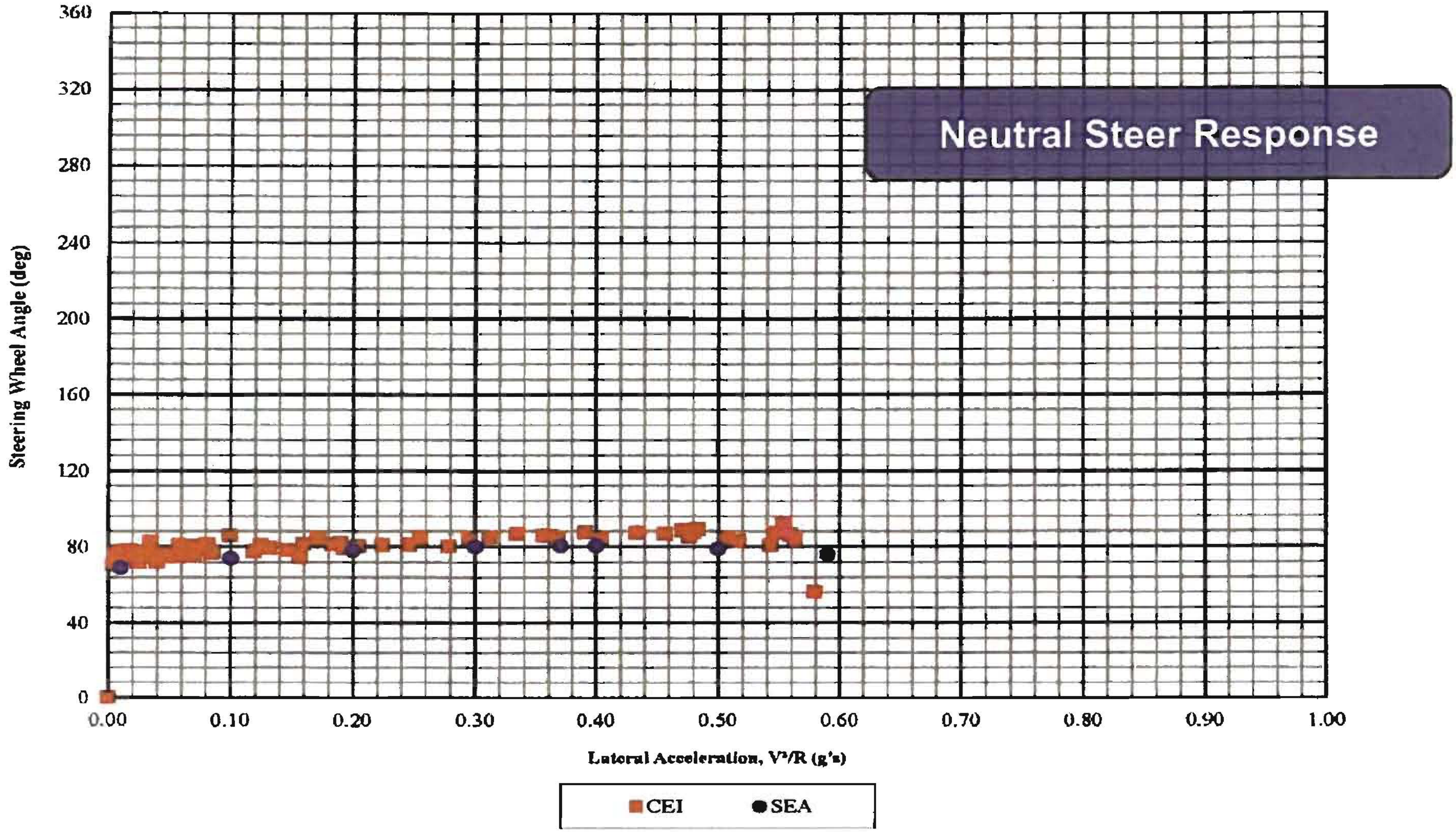
On-Highway Steering / Vehicle A



On-Highway Steering / Vehicle A

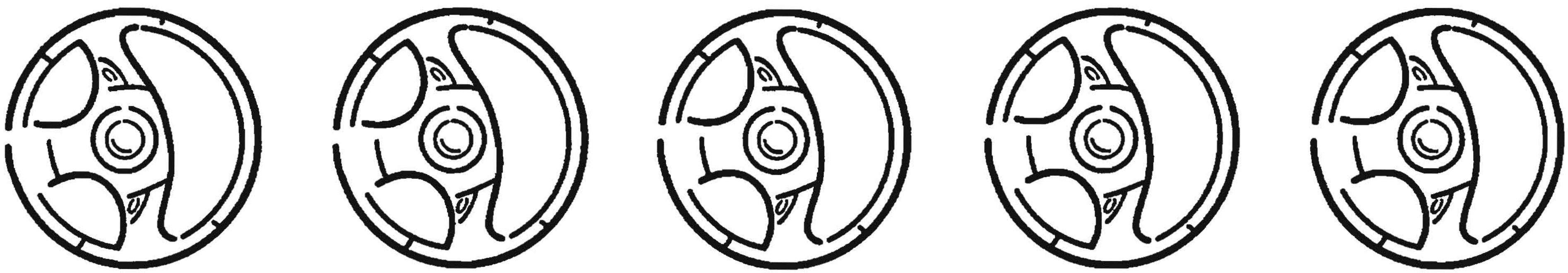
Two-Wheel Drive on Concrete – Decreasing Understeer

On-Highway Steering / Vehicle D



On-Highway Steering / Vehicle D

Two-Wheel Drive on Concrete – Neutral Steer Response



0.00 g | 0.20 g | 0.30 g | 0.40 g | 0.50 g

On-Highway Steering Results

- Generally consistent results independent of testing methodology that satisfy CPSC/SEA-stated objective of being both accurate and repeatable

- SWA adjustments are small and do not relate to a machine's crash avoidance capacity

- Inappropriate for use as a standard or metric due to lack of correlation to crash risk or crash involvement

Off-Highway Steering Characterization

Off-Highway Steering Results

- Measurement of SWA as a function of vehicle lateral acceleration on dirt

- Total of 264 individual configurations evaluated
  - ✓Eleven machines (A through K)
  - ✓Two loading configurations (SEA-defined)
  - ✓Two orientations (CW and CCW)
  - ✓Two diameters (50’ radius and 100’ radius)
  - ✓Three driveline modes (2WD, 4WD, 4WDL)

- SEA did not perform testing on off-highway surfaces, so direct comparisons could not be performed

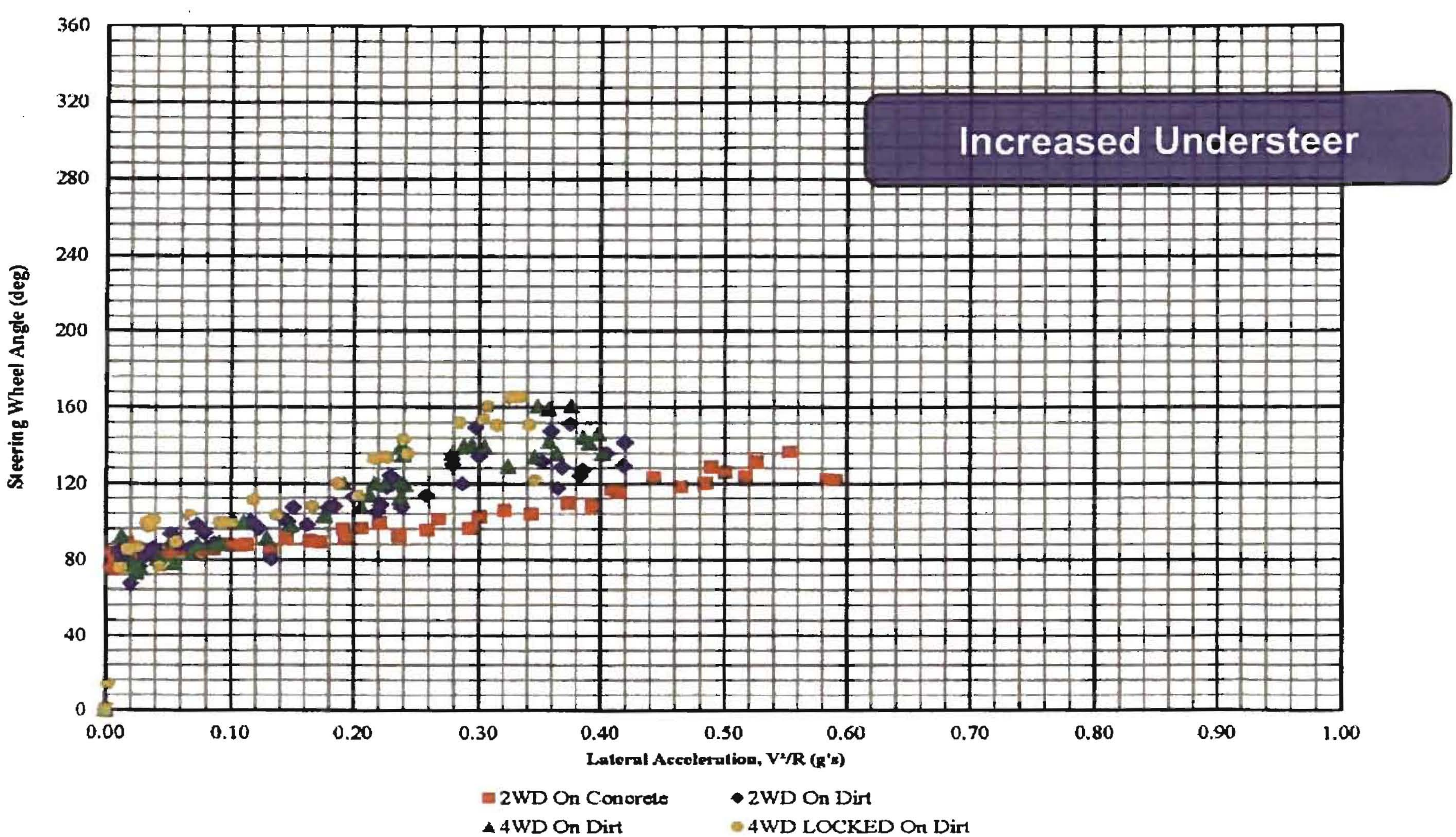
Why Test on Dirt?

- Testing on on-highway surfaces is a specifically warned-against behavior and is not the intended operating environment for these machines

- Testing on off-highway surfaces more accurately reflects the intended usage and utility of the machines

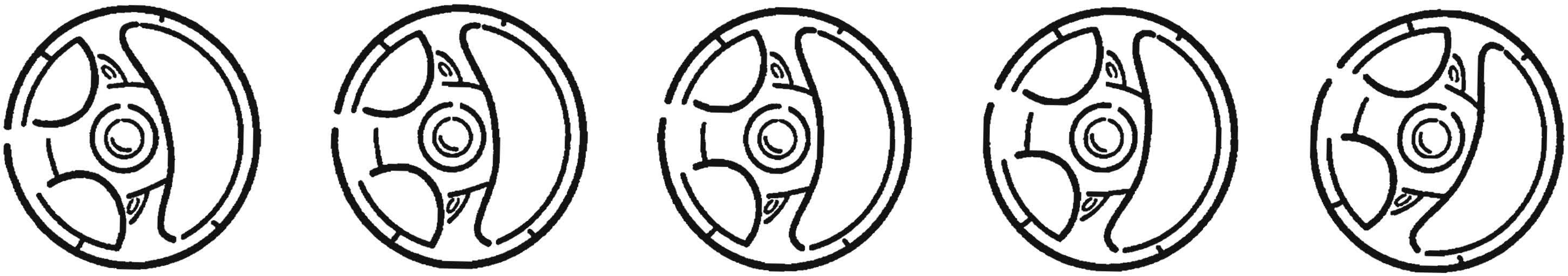
- Testing in driveline modes with increased tractive effort more accurately reflects the intended functionality of the machines on these surfaces

Off-Highway Steering / Vehicle E



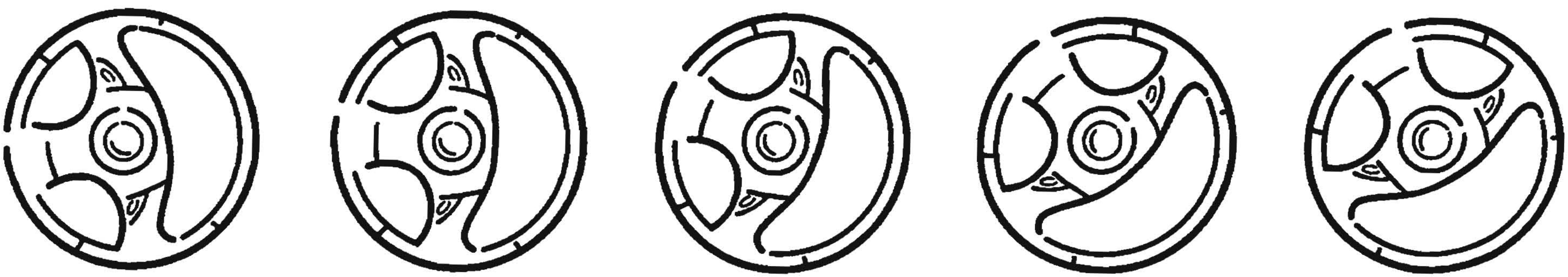
Off-Highway Steering / Vehicle E

Two-Wheel Drive on Concrete – Understeer Response



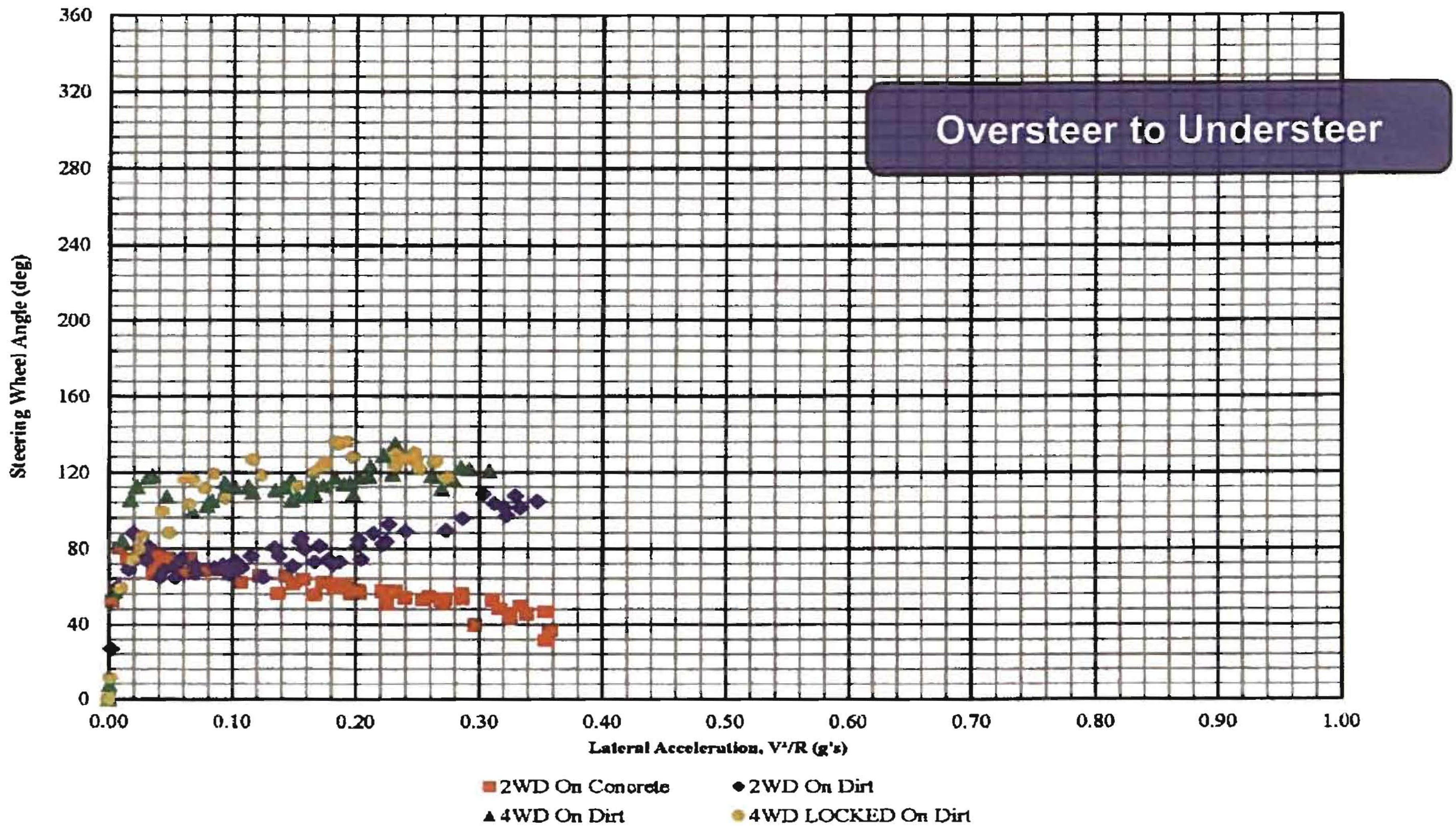
0.00 g | 0.10 g | 0.20 g | 0.30 g | 0.40 g

Four-Wheel Drive on Dirt – Increased Understeer Response



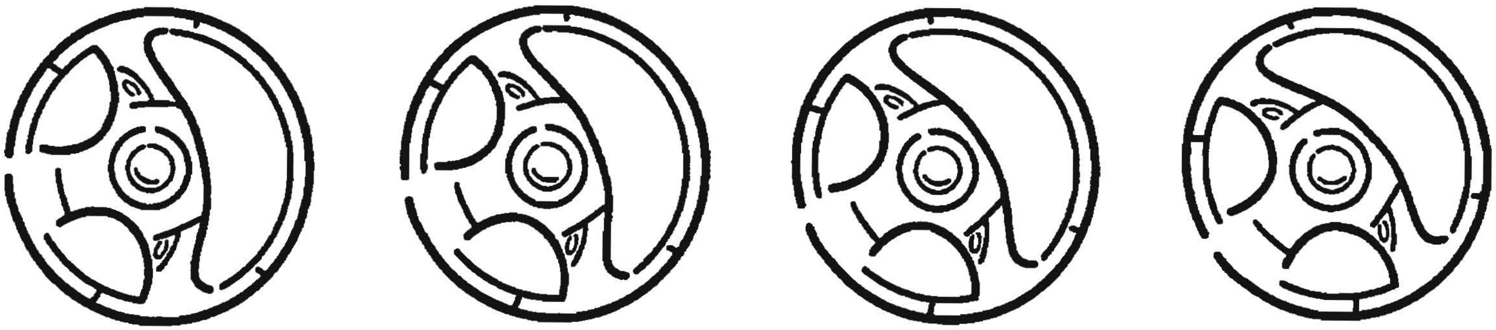
0.00 g | 0.10 g | 0.20 g | 0.30 g | 0.40 g

Off-Highway Steering / Vehicle D



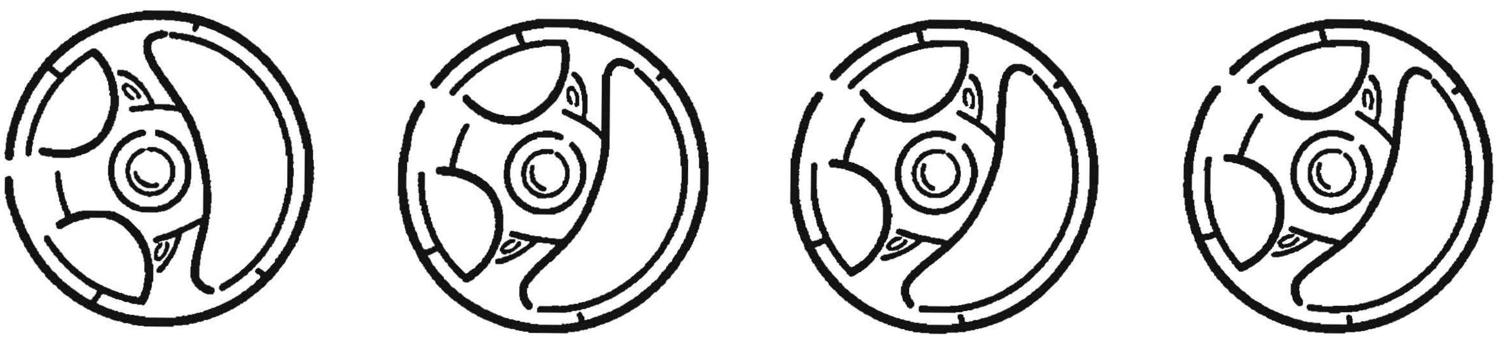
Off-Highway Steering / Vehicle D

Two-Wheel Drive on Concrete – Oversteer Response



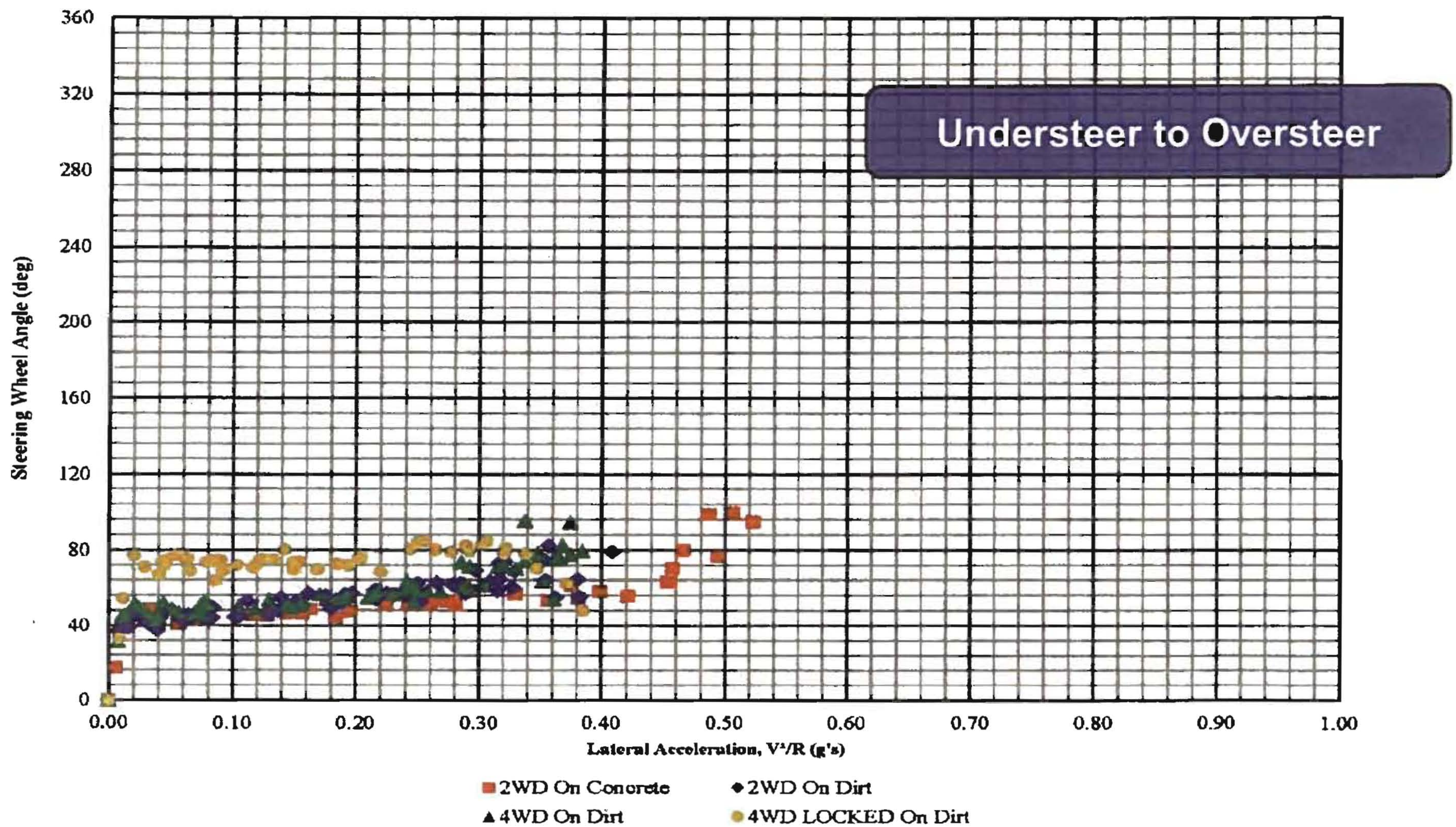
0.00 g	0.10 g	0.20 g	0.30 g	N/A 0.40 g

Four-Wheel Drive on Dirt – Understeer Response



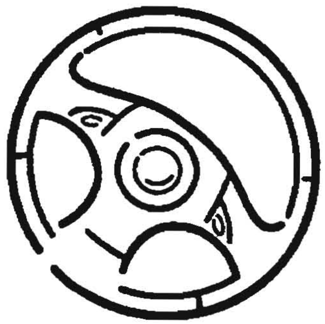
0.00 g	0.10 g	0.20 g	0.30 g	N/A 0.40 g

Off-Highway Steering / Vehicle J

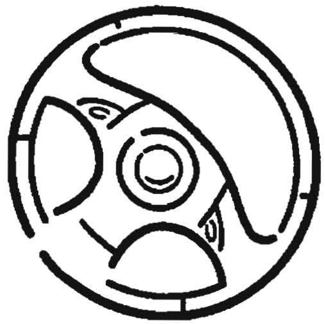


Off-Highway Steering / Vehicle J

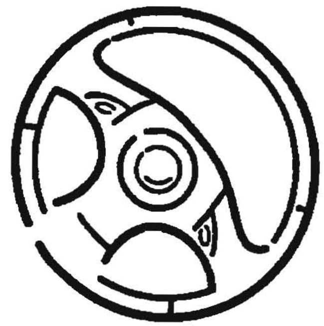
Two-Wheel Drive on Concrete – Understeer Response



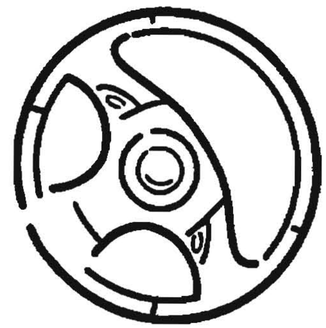
0.00 g



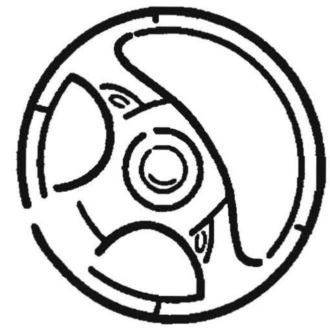
0.10 g



0.20 g

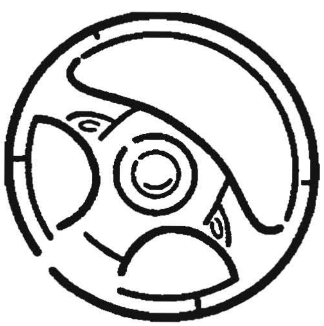


0.30 g

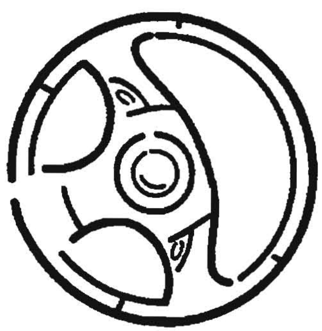


0.40 g

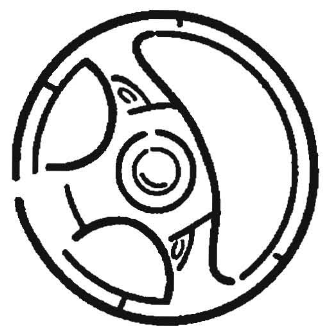
Four-Wheel Drive Locked on Dirt – Oversteer Response



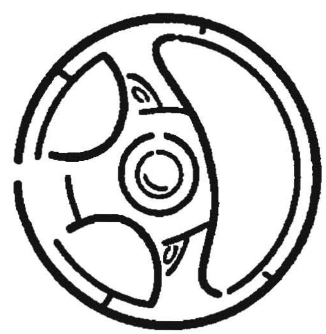
0.00 g



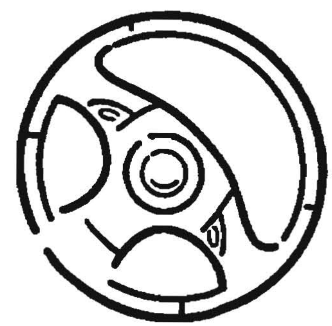
0.10 g



0.20 g

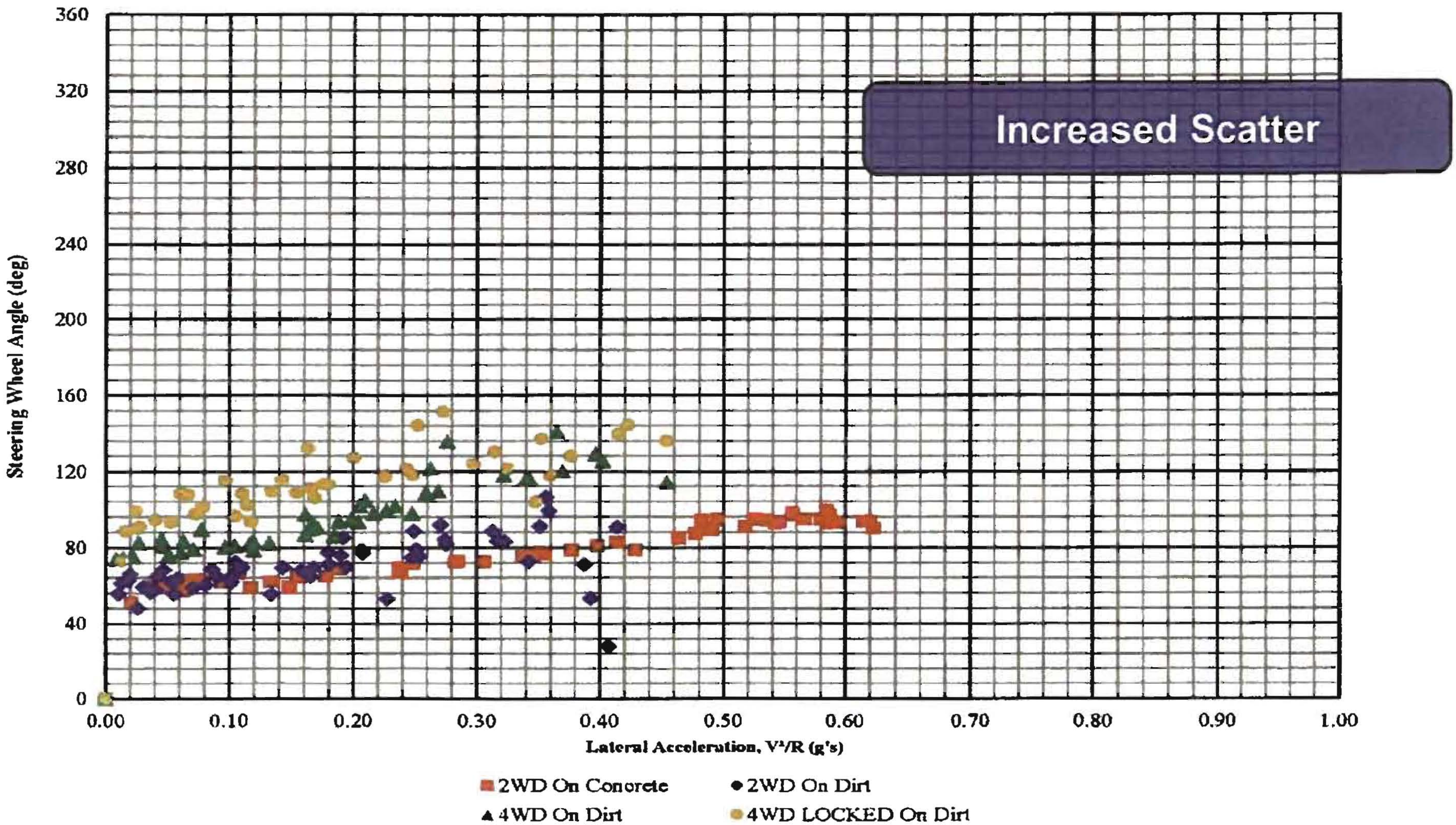


0.30 g



0.40 g

Off-Highway Steering / Vehicle C



Off-Highway Steering Results

- Does not always correlate to a machine's measured on-highway steering characteristic
- SWA adjustments are small and do not relate to a machine's crash avoidance capacity
- Inappropriate for use as a standard or metric due to lack of correlation to crash risk or crash involvement
- May dictate compromises in vehicle design that can reduce utility and/or crash avoidance capacity

Summary

Summary – SSF and TTA

- SSF/K_{st} and TTA are static vehicle parameters that can be measured accurately and reliably as long as key test variables are defined and controlled

- Generally relates to a machine's crash avoidance capacity

	Average Difference	Maximum Difference
Static Stability Factor (K_{st})	~2%	~5%
Tilt Table Angle	~3%	~14%

Summary – J-Turn SWA and Ay

- J-Turn SWA and Ay are dynamic test parameters that cannot be reproduced accurately or reliably due to uncontrollable variations in specific methodologies

- Inappropriate for use as a standard or metric due to large test-to-test variability

	Average Difference	Maximum Difference
J-Turn Steering Wheel Angle	~14%	~63%
J-Turn Minimum Lateral Acceleration	~13%	~37%

Summary – Steering Characterization

- **On-highway steady-state steering characterization can be performed accurately and reliably, but…**
  - ✓**The characteristic can change from understeer to oversteer (and vice versa) when evaluated on off-highway surfaces**
  - ✓**SWA adjustments are small and do not relate to a machine's controllability or crash avoidance capacity**

- **Inappropriate for use as a standard or metric due to lack of correlation to crash risk or crash involvement**

Introduction
DRE Task

- Evaluate the effectiveness of the ROV Occupant Retention Systems (ORS) in rollover accident events.
- Evaluate the current ANSI-ROHVA standard with respect to occupant protection including kinematics and retention in 90 degree rollover events.

Background

Active Versus Passive Occupants

(Carhart and Newberry, 2010)

- ROV occupants are active riders that counter-posture and brace against inertial forces.
- Active muscle response combined with three point seat belts have been shown to keep occupants within ROVs in static 90 degree roll evaluations.

An example of a ROV passenger counter-posturing in a left-hand turn

Carhart M, Newberry W, Biomechanical Analysis of Passive and Active Occupant Responses During Rhino Riding and 90-Degree Tip-Over Events, 3:09-MD-2016-JBC, MDL No. 2016, 2010)

Background

Active Versus Passive Near Side Occupants

- During pre-trip vehicle dynamics near side surrogate occupants bend their necks away from the vehicle periphery resisting inertial head motions. *(Yamaguchi et al., SAE Paper 2005-01-0302)*
- Anthropomorphic Test Devices (ATDs) are passive occupants
- Leading up to 90 degree rollover events ATDs are…
  - reasonable estimate of near side occupant lateral motions
  - likely overestimate head excursion.

From Yamaguchi et al., 2005 (SAE Paper 2005-01-0302)

Background

Seat Belt

- Seat belts are the most effective injury mitigating safety device in rollover accidents.
- Seat belts offer effective protection against ejection and injury in rollover accidents.
  - Risk of ejection *(NHTSA DOT HS 810 741)*
    - 33% for unrestrained SUV occupants
    - Less than 1% (0.33%) for SUV restrained occupants
  - 98.6% of all seat belted occupants in SUV rollover crashes do not receive serious or fatal injuries *(Malliaris and Diggs, SAE Paper 1999-01-0063)*

Background
Seat Belts

- Seat belted ATDs (passive occupants) remain within ROVs during dynamic lateral deceleration sled tests inducing a 90 degree roll event.

From Carhart and Newberry, 2010

ANSI – ROHVA ORS Evaluation

DRE Approach

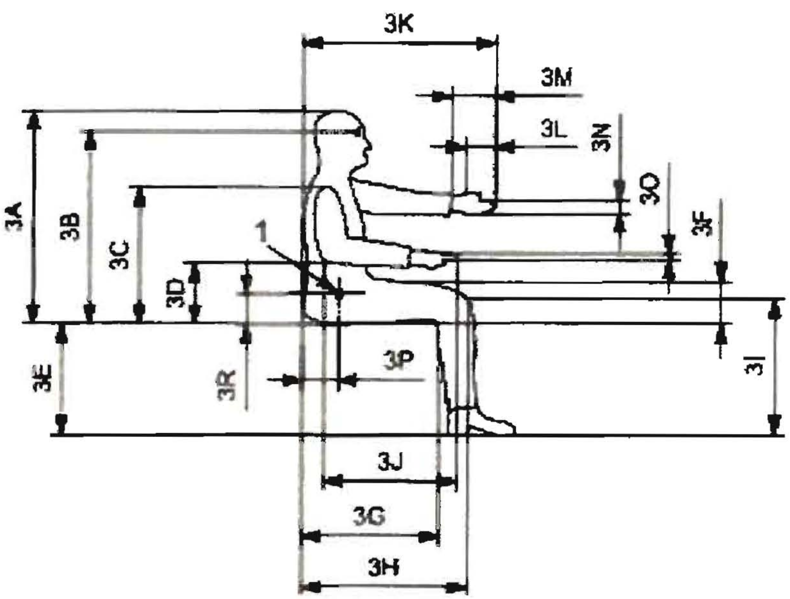
- ROPS / Seat belt system performance evaluation
  - ROPS Geometry
  - Rollover simulations
  - Computer modeling of belted/zone 1 retention
- Performance based requirement evaluation
  - Acceleration environment comparison
  - Hand grip force evaluation
- Zones 1, 2, and 3 barrier requirement evaluations
  - Barrier geometry
    - Occupant anthropometry
    - Computer simulation
  - Barrier strength
    - Computer simulation

ROPS Geometry Analysis
Exemplar Scanning

ROPS Geometry Analysis

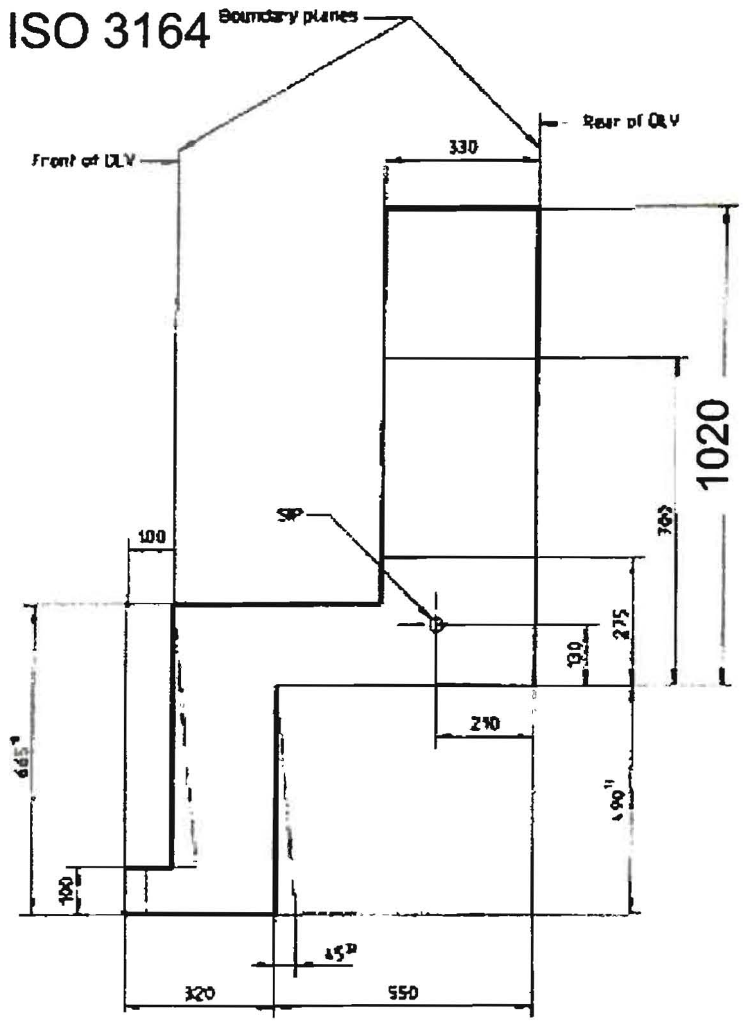
Methodology

ISO 3411



95th % Seated Height
976 + 50 (helmet) = 1026 mm

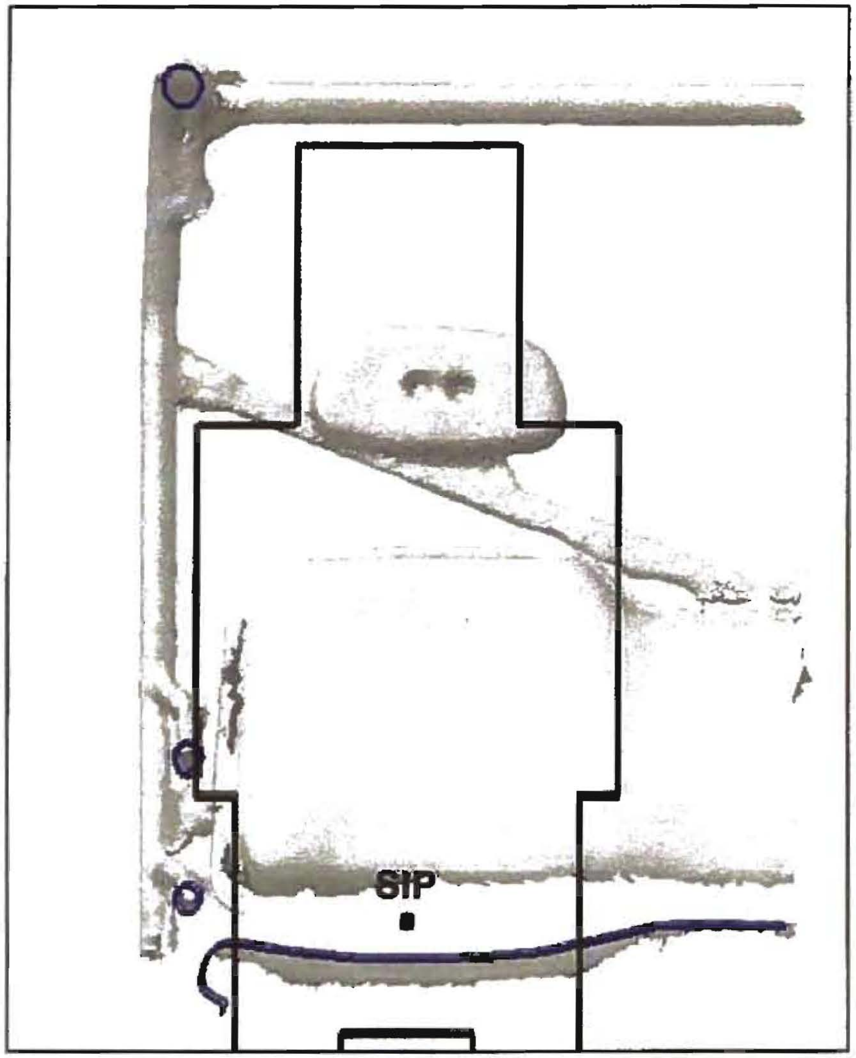
ISO 3164



Seated Height
1020 mm

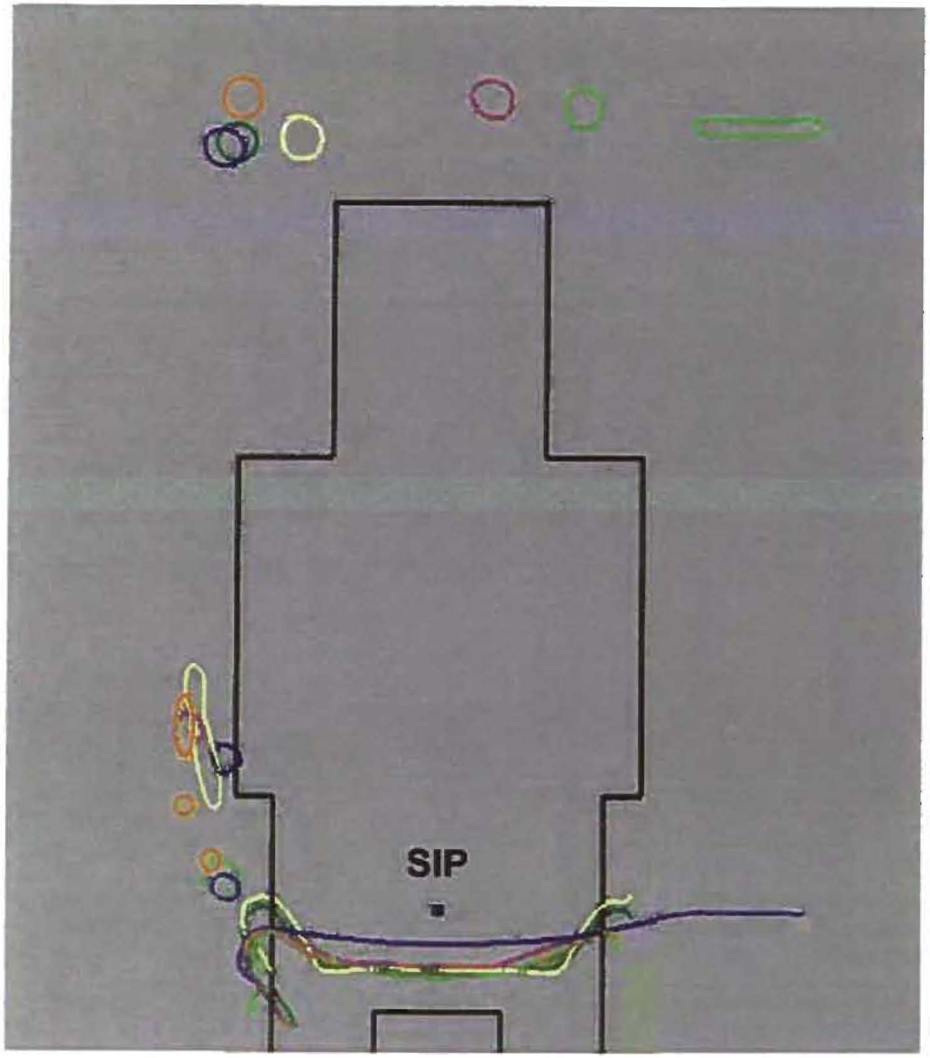
ROPS Geometry Analysis

Cross Section Through Seat Index Point



ROPS Geometry Analysis

Summary



ANSI-ROHVA standard specifies ROPS force and energy performance requirements. This has resulted in ROPS initial geometries well outside the Deflection Limiting Volume (DLV).

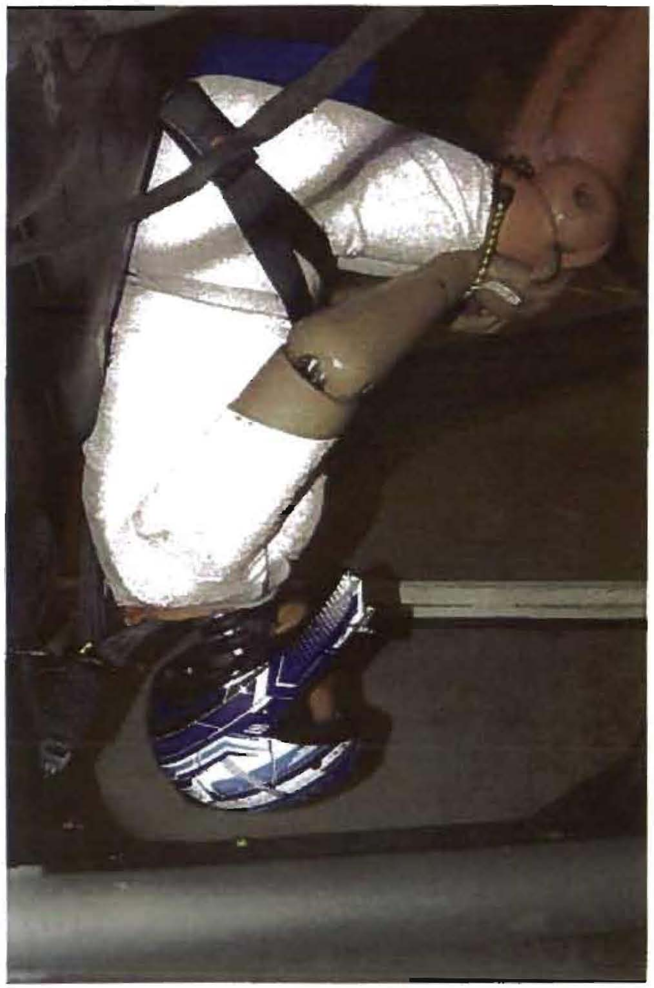
Quasi-Static Rollover Simulations

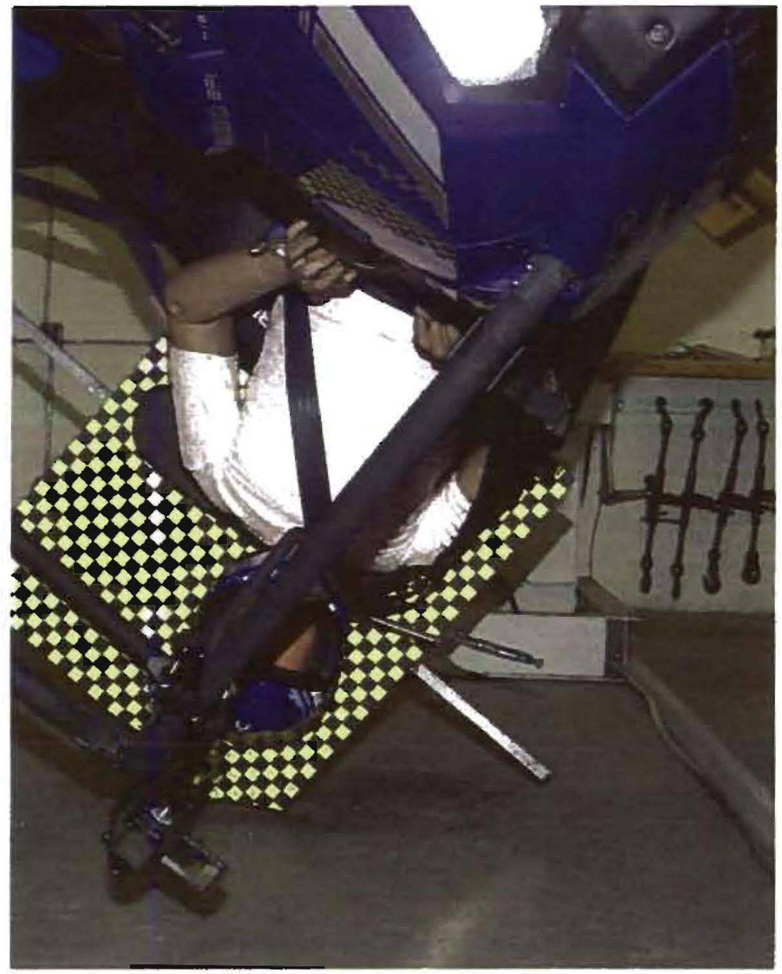
Setup

- Centered ATD hips and buttocks against seat back
- Route available seat belt and adjust lap belt loop with fingers between ATD pelvis and belt
- ATD hands secured to knees
- Rotate table to potential head-ROPS interaction angle.
- Allow seat belt retractor to lock via table tilt angle.
- Repeat above process three times

Quasi-Static Rollover Simulations

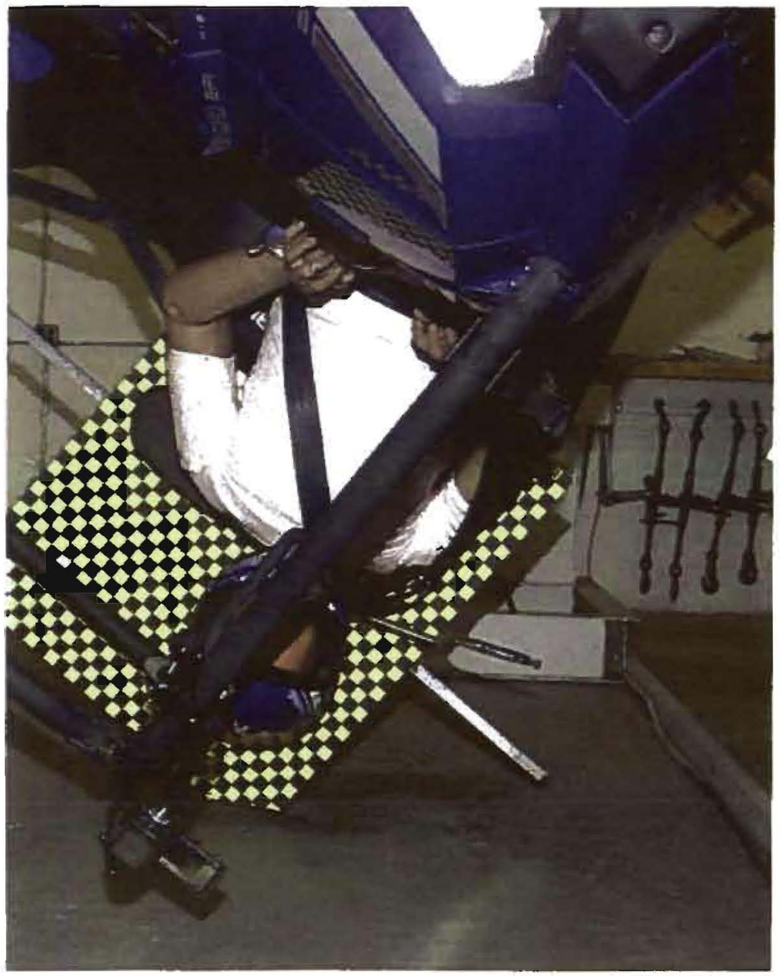
Results – Sample Inverted Position

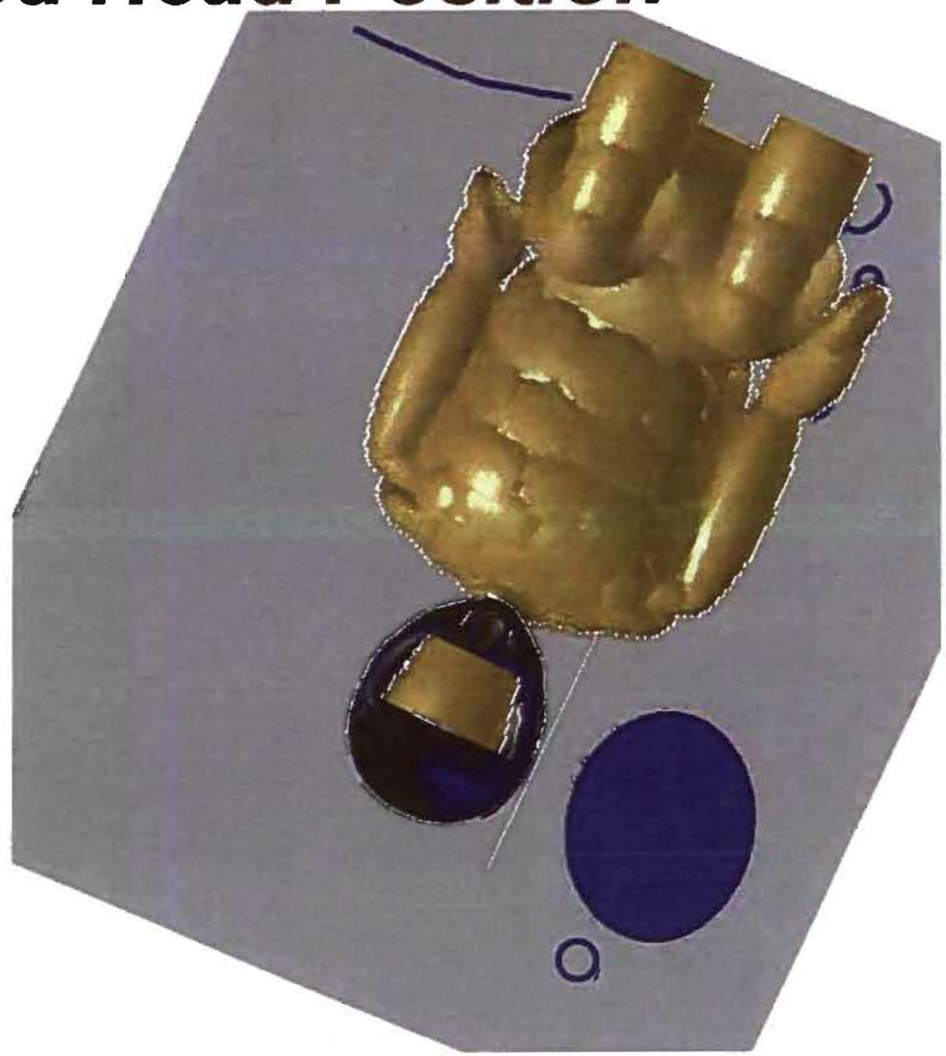




Quasi-Static Rollover Simulations

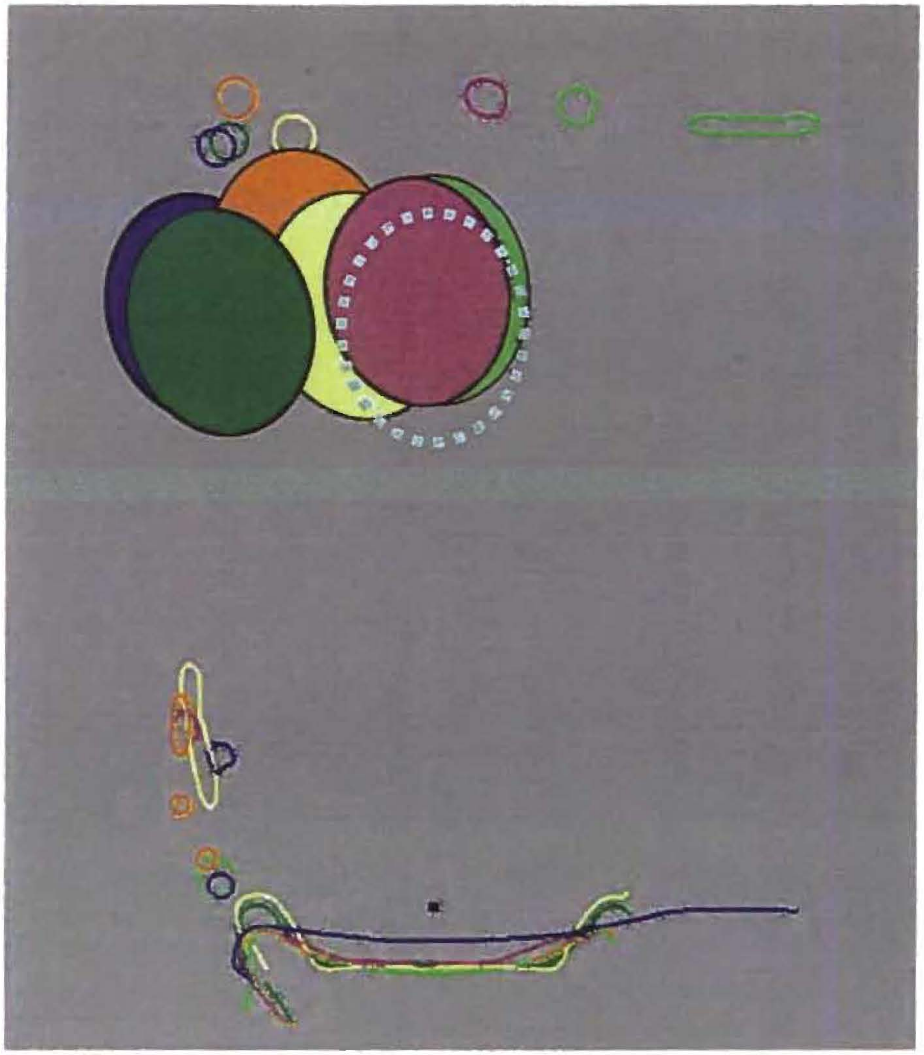
Results – Inverted Head Position

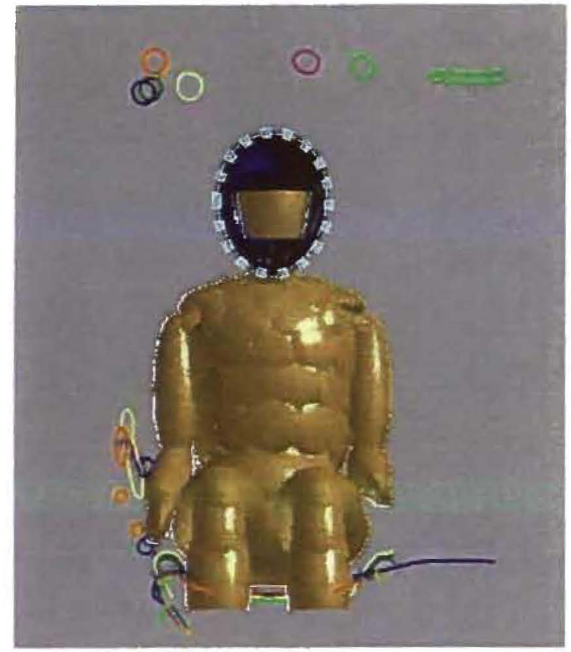




Quasi-Static Rollover Simulations

Results – Inverted Head Positions



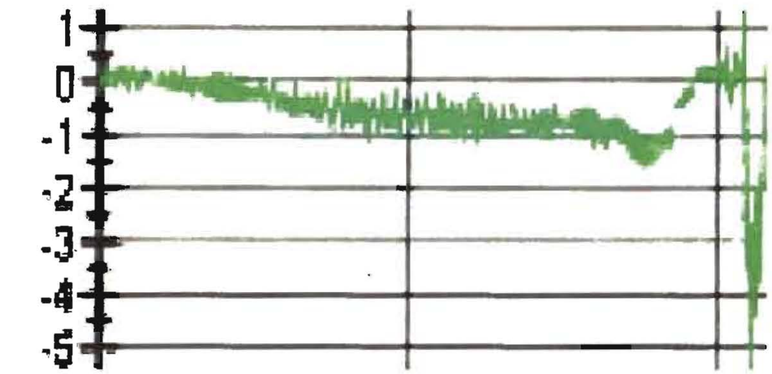


MADYMO
Modeling Setup

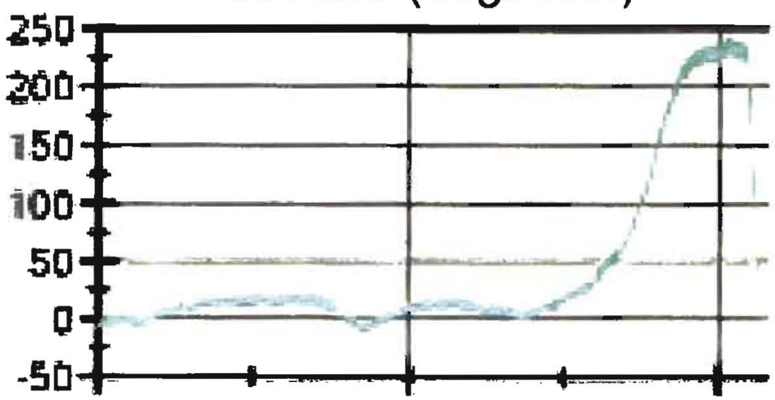
- MADYMO Version 7.3
- Generic vehicle model from scans
- Hybrid III Series ATDs
  - 95% Male (6'2" 223 lbs)
  - 50% Male (5'9" 171 lbs)
- Sliding Friction (μ) = 0.5
- Generic belt restraint properties
- Seat has modest contour/sculpting

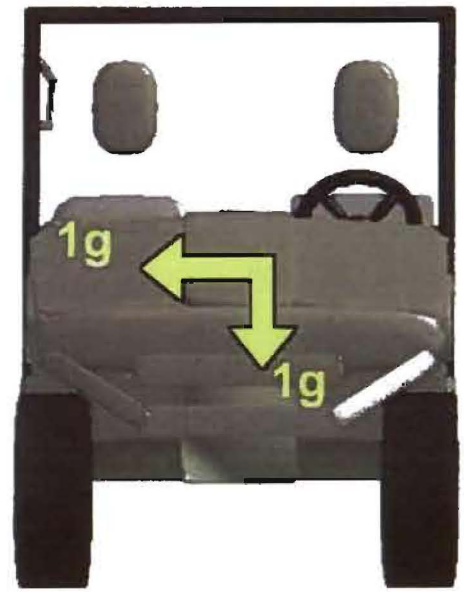
MADYMO
Acceleration Environment

Lateral Acceleration (g)



Roll Rate (deg./sec.)





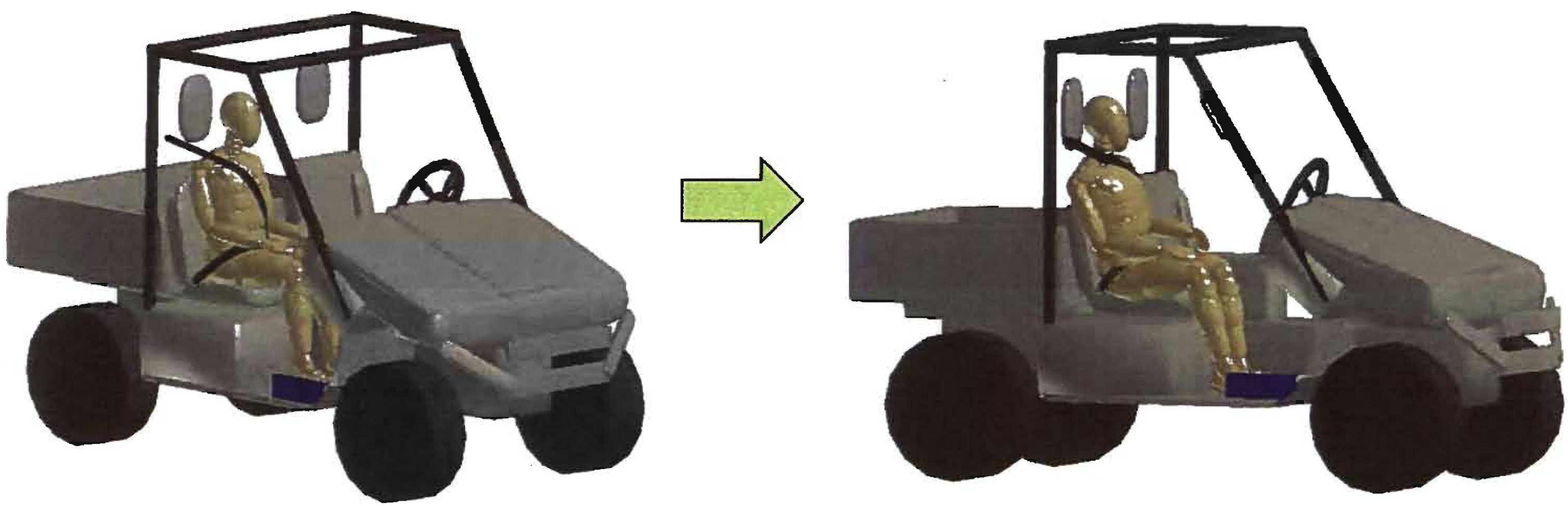
Gravitational and lateral accelerations are step inputs in MADYMO simulation

Change in body roll angle is not simulated in MADYMO increasing the relative lateral motion between the occupant and ROV

Test 2 From Warner and Bready, SAE Paper 2011-01-1117

MADYMO

Restrained 50th % Male ATD

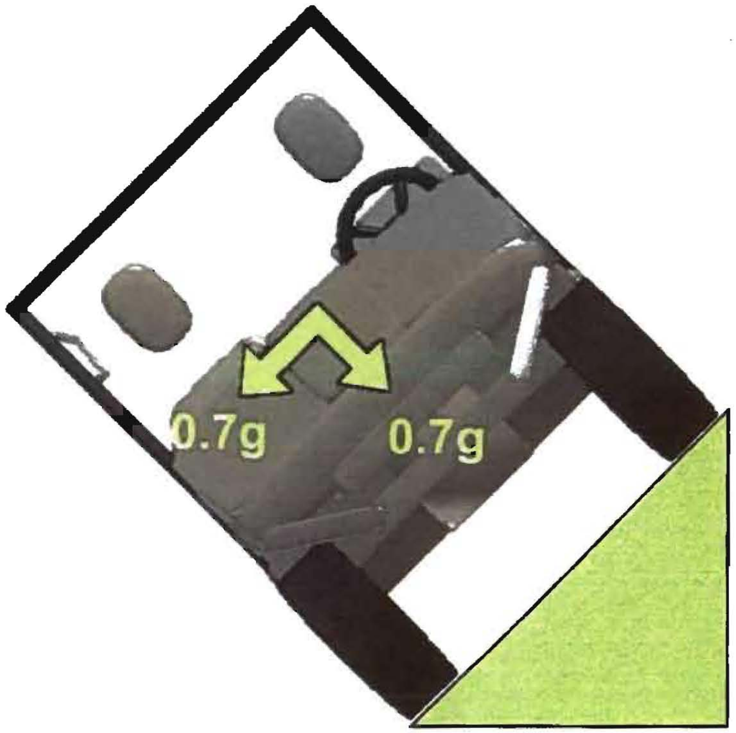


Steady state zone 1 force is 85 N (~19 lbs.)

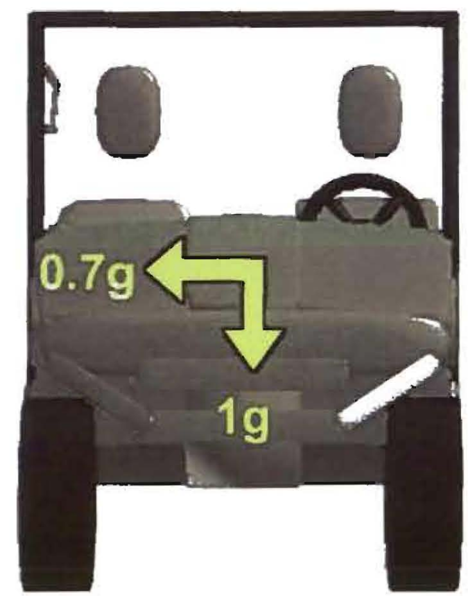
Hand maintained on right thigh with a steady state force of 50 N (~11 lbs.)

Performance Based Tilt Test

45 Degrees Static Evaluation



Static Tilt



Pre – Roll Dynamics

45 degree static tilt is conservatively comparable to 0.7 g pre-roll dynamics

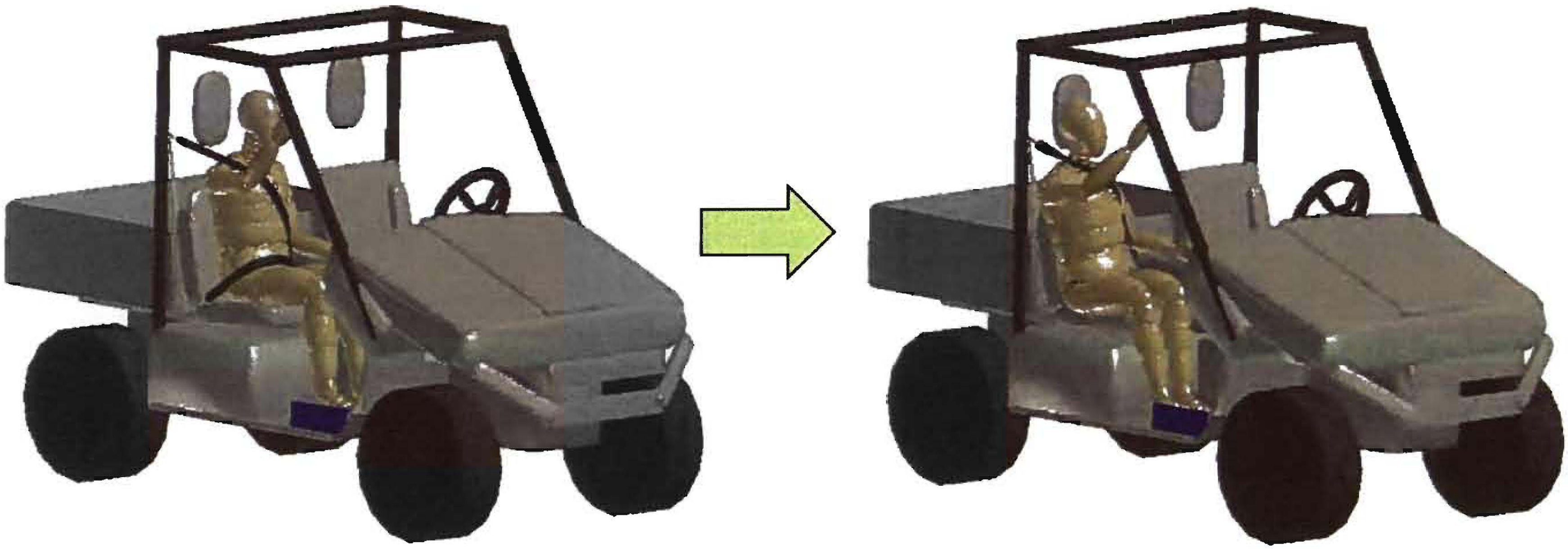
Tilt Test – Reasonable Grip Force

MADYMO - Restrained 50th % Male ATD

- Outboard hand connected to hand hold using a Kelvin (spring/dashpot) element.
- Hand hold location accentuates arm tensile loading.
- Zone 1 barrier included.

Tilt Test – Reasonable Grip Force

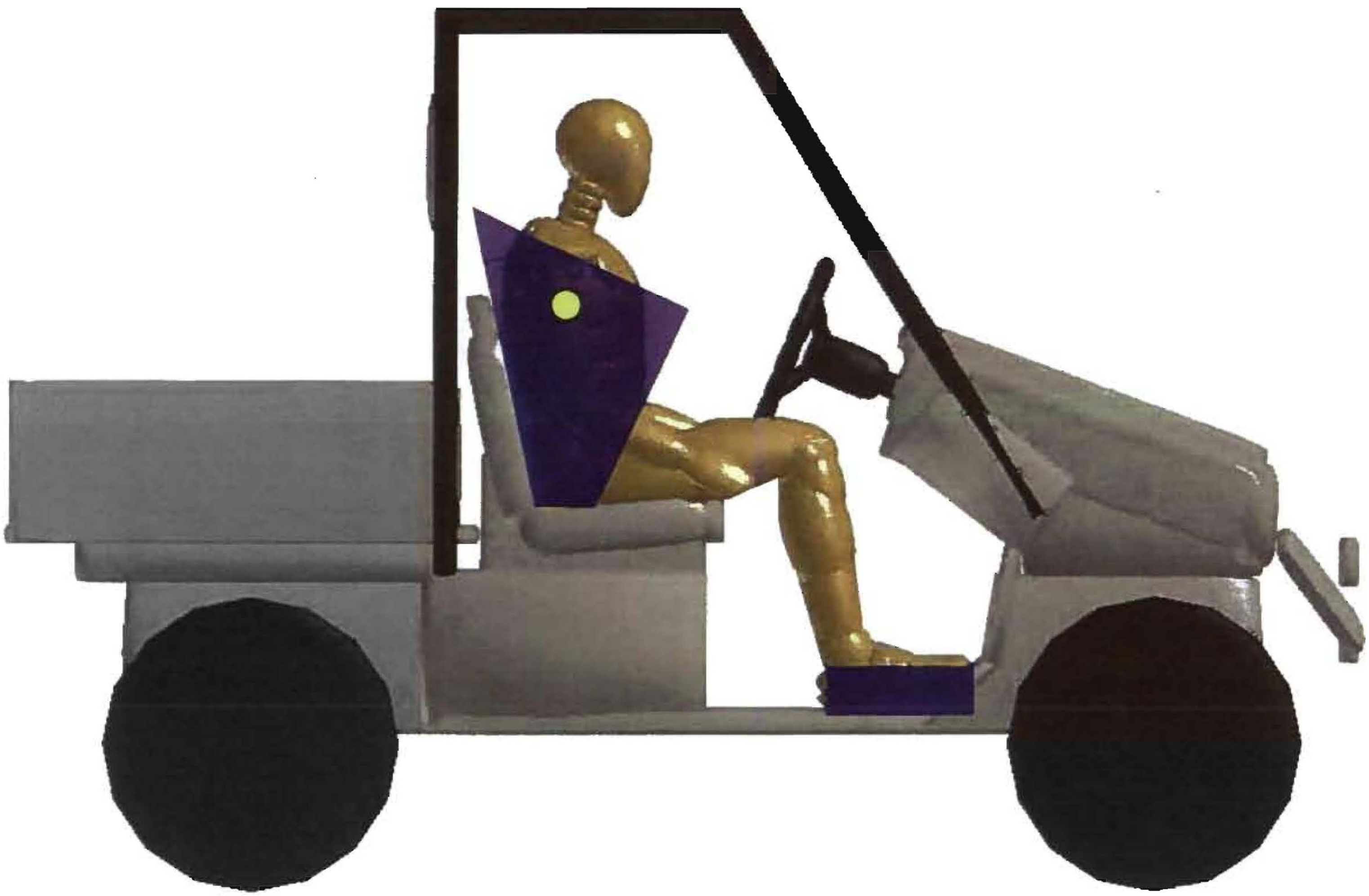
MADYMO - Restrained 50th % Male ATD



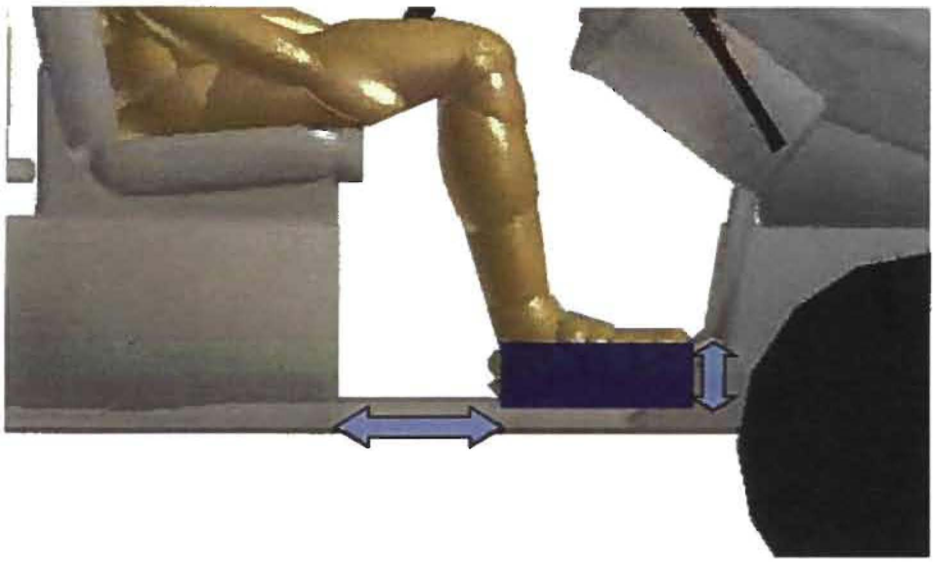
Steady state hand hold force 150 N (~34 lbs.) or 20% of body weight.
This is well within occupant capability and consistent with findings of Carhart and Newberry (2010).
Steady state zone 1 force is 100 N (~22 lbs.).

Construction Based Barriers

95th % Male ATD – Generic Vehicle Model



Barrier Dimensions
Zone 1 Geometry

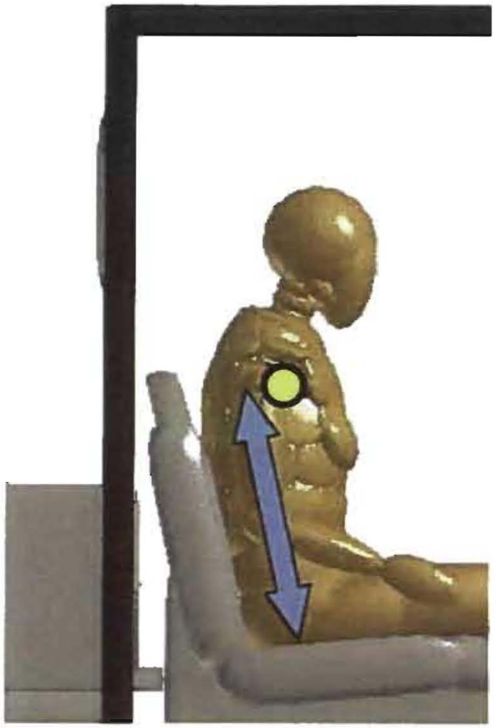


4" Height
- Ankle height
  - •3.9 – 4.7 in. (ISO 3411)
  - •2.5 – 3.7 in. (Tilley)

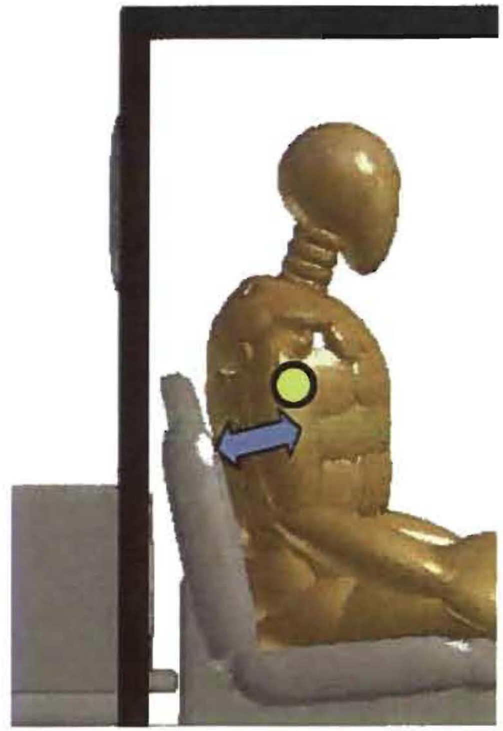
9" Opening
- Foot length
  - •9.8 – 12.2 in. (ISO 3411)
  - •9.9 – 13.2 in. (Tilley)

ISO 3411. Earth-moving machinery — Physical dimensions of operators and minimum operator space envelope (5th-95th % Operators)
Tilley AR. The Measure of Man and Woman, Henry Dryfus and Associates, New York, 1993 (1st % female to 99th % male)

Barrier Dimensions
Zone 2 Geometry

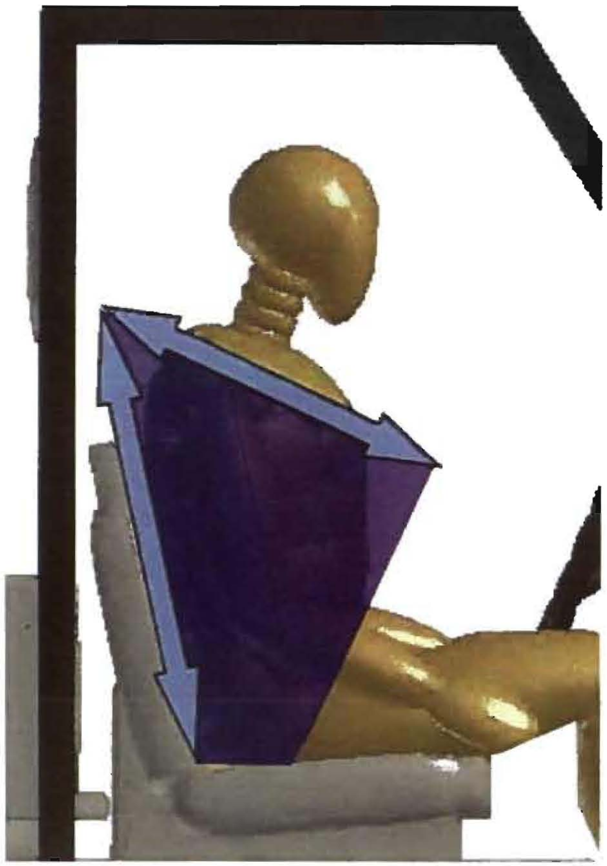


17” along Seat Back
- Shoulder Height
  - 20.9 – 25.6 in. (ISO 3411)
  - 20.8 – 26.6 in. (Tilley)



6” Perpendicular from Seat Back
- Chest Depth
  - 8.3 – 11 in. (ISO 3411)
  - 7.5 – 12 in. (Tilley)

Barrier Dimensions
Zone 3 Geometry

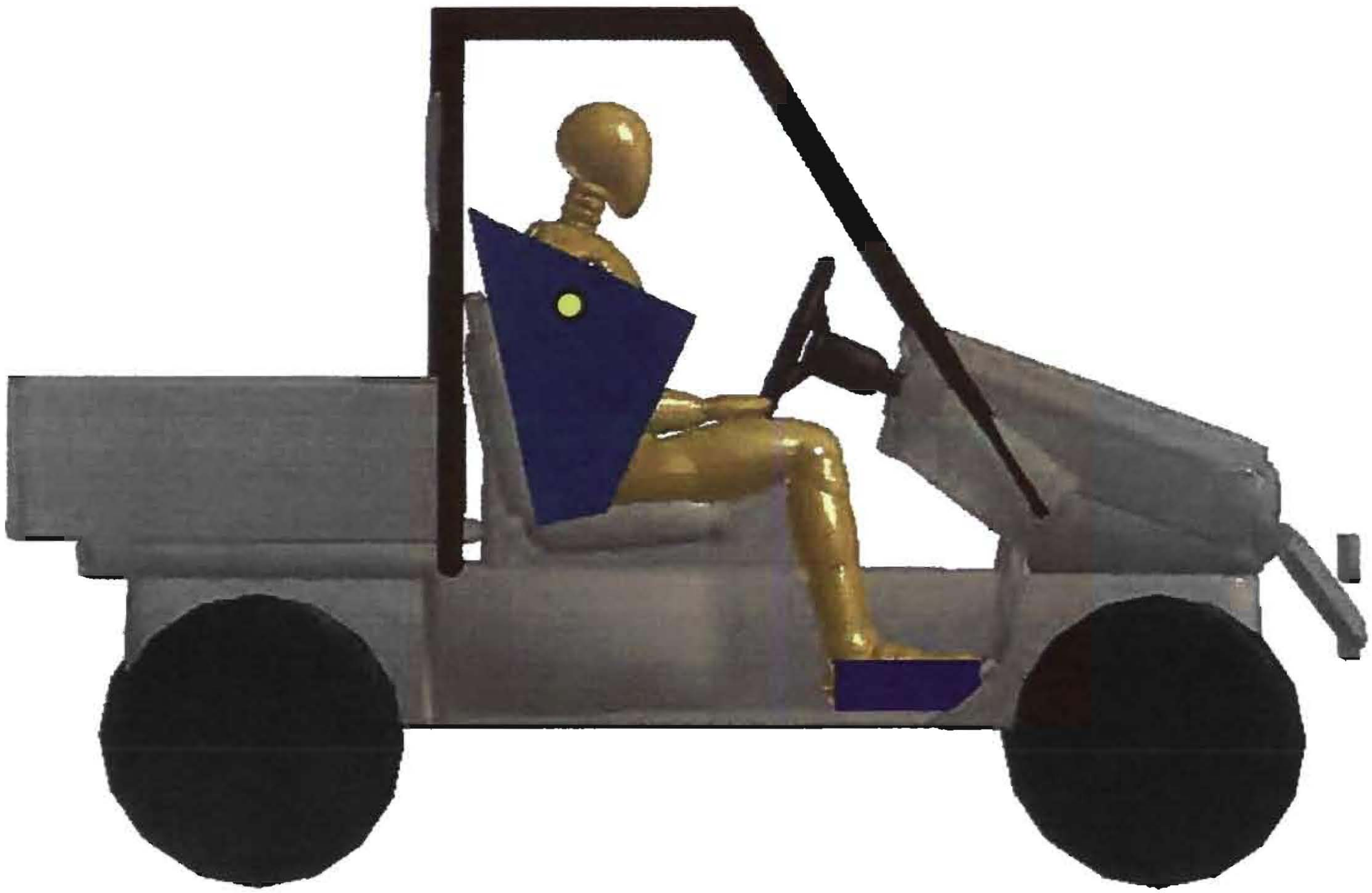


26" Along Seat Back
•Shoulder Height
    •20.9 – 25.6 in. (ISO 3411)
    •20.8 – 26.6 in. (Tilley)

19.7" @ 25 deg. from Horizontal
•Upper Arm Length
    •9.2– 12.3 in. (Tilley)
•Buttock to Shoulder Joint Depth
    •4 – 5.3 in. (Tilley)

Barrier Force Requirements

MADYMO - 95th % Male ATD Not Seat Belted



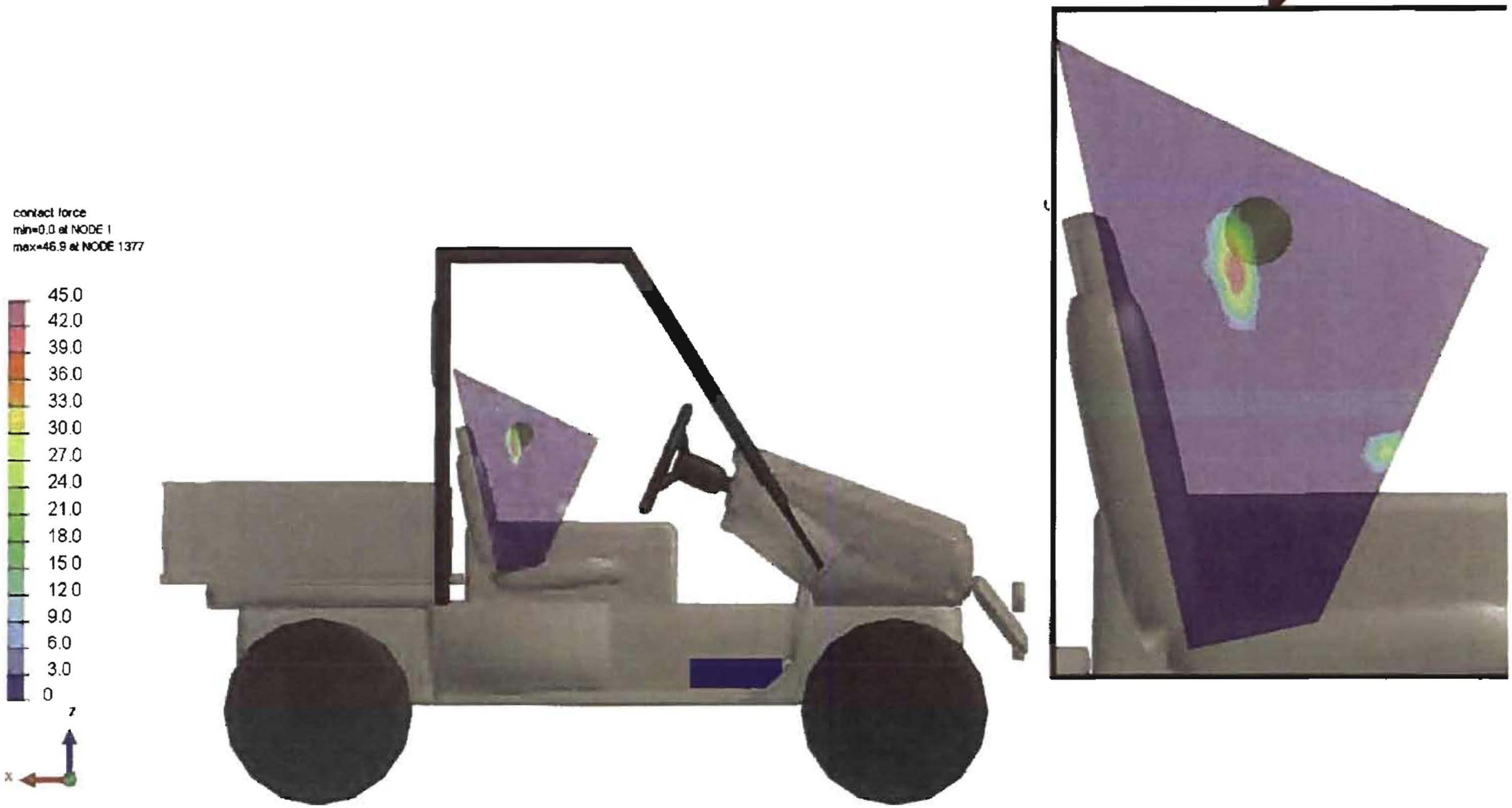
Barrier Force Requirements

MADYMO - 95th % Male ATD Not Seat Belted

Steady State Zone 1 Contact Force 225 N (~50 lbs)
Steady State Zone 2/3 Contact Force 700 N (~157 lbs)
Barrier force requirements are sufficient to retain 95th male ATD

Zone 2 Barrier Location

MADYMO - Pressure Contour Analysis



Summary of Initial Findings

- The ROPS / Seat Belt / Zone 1 system provides effective restraint and protection to helmeted occupants.
- Zones 1, 2 and 3 construction based barriers have a rational basis
  - Geometry based on anthropometry of population
  - Strength requirements for zones are reasonable
  - MADYMO simulations show effectiveness of the zone barriers
- Zone 4 – ROPS design and seat belt use are effective in mitigating the potential for head crush injuries.

DUAL INDEPENDENT ANALYSES: HUMAN FACTORS AND VEHICLE DYNAMICS

- Two teams of human factors and vehicle dynamics experts:
  - Applied Safety and Ergonomics
  - Carr Engineering
- Hundreds of hours of analysis
- Independent assessment followed by joint analysis

In-Depth investigations

- Analysis of 171 complete IDIs
  - Examined IDIs to assess potential effects of changes in crash avoidance features
  - Did not include duplicates or terminated incomplete IDIs
- Range of incident dates: April 2004 to September 2010
- Vehicle model years: 1999 to 2010

Sample Circumstances Before Loss of Control

- Drivers and passengers with alcohol
- Youngsters in groups without adults present
- Ride areas with obstacles/extreme terrain
- Driving on roads: collisions, impaired or without license
- Recognition of risky behaviors or potential concerns
- Unsupervised or unauthorized use or location of use

CRITERIA FOR CRASH AVOIDANCE CATEGORIES

- **Highly Unlikely or Unlikely Per Investigation**
  - The circumstances of the crash were unrelated to the crash avoidance capacities of the machine, the operator was intentionally engaging in risk-taking behavior or stunts, or the authority or agency investigating the incident concluded that the operator was making unreasonable and/or inappropriate driving decisions.
- **Inconclusive**
  - It is possible, but unclear, that different design attributes could have mitigated the crash.
- **Insufficient Information**
  - Not enough is known about the crash scenario to draw a definitive conclusion.

EXAMPLES OF CRASH CIRCUMSTANCES HIGHLY UNLIKELY OR UNLIKELY PER INVESTIGATION TO BE RELATED TO CRASH AVOIDANCE

LAUNCHING:

"At that time, he approached the truck stop and a 30 to 40 foot raised dirt embankment. The victim failed to apply the brakes or stop causing all four wheel to leave the ground and the vehicle became airborne. The victim's vehicle impacted the upper rear portion of a parked tractor-trailer and fell to the ground." - 091118HWE8524

STRUCK BY OTHER ON-ROAD VEHICLE:

"Utility vehicle that was struck by an oncoming truck" - 100113HCC2316

Examples of crash circumstances highly unlikely or unlikely per investigation to be related to crash avoidance

Collision with fixed object:

"The [vehicle] approached the gate and crashed into the portion which was extended into the road." - 080415HWE7319

Intentional stunt:

"The father was attempting to spin the UTV to make donuts in the dirt when one of the UTV wheels caught in a rut and the UTV tipped over toward the passenger side." – 091123HWE8536

Examples of crash circumstances highly unlikely or unlikely per investigation to be related to crash avoidance

Loss of control leading to rollover in a ditch:

"…a one vehicle Off-Road/ATV accident on County Road…[redacted] was distracted by handing a can of root beer to [redacted] then looked back to the road and saw that they were going off of the road. She yelled, [redacted] to get her attention, but they were already off of the roadway and in the ditch." - 100601HNE0366

Use on extreme terrain:

"At some point, the decedent attempted to climb a hill which was approximately 70-degrees incline. The OHV tipped rearward and to the right then rolled over." - 090728HCC3816

EXAMPLES OF CRASHES CIRCUMSTANCES WHERE THERE WAS INSUFFICIENT INFORMATION TO MAKE A DETERMINATION

INSUFFICIENT INFORMATION:

"[Driver] attempted to pass the van traveling in front of him, [and] the UTV which he was driving flipped." – 090126CCC2285

"The Witness states that the victim went to turn around and the vehicle overturned" – r070430HNE2274

"For unknown reasons (possibly due to the rough terrain) P1 lost control of V1" – 081030CCC3081

EXAMPLES OF CRASH CIRCUMSTANCES WHERE THE EFFECT OF ADDITIONAL CRASH AVOIDANCE FEATURES IS INCONCLUSIVE

DESCRIPTION OF OPERATION CAUSING A CRASH:

"While riding as a passenger in a [UTV], side by side ATV, a slow gradual turn to the left causing the vehicle to roll over on the passenger side." – 080905CNE3738

"The driver and two passengers were traveling on "a slight uphill grade" when the driver "initiated a slight right hand turn." The vehicle "tipped over a quarter turn onto its driver's side."" – 090508CCC1699

EXAMPLES OF CRASH CIRCUMSTANCES WHERE THE EFFECT OF ADDITIONAL CRASH AVOIDANCE FEATURES IS INCONCLUSIVE

DESCRIPTION OF OPERATION CAUSING A CRASH:

…had been creeping along at about 2-5 mph when he overturned. He was braking at the time and believes that his back wheels lock (sic) up, but he does not know if his front wheels may have been turned to the left or right. He stated that as the back wheels locked up, the back end of the vehicle began to slide sideways and within one flow the vehicle overturned onto the passenger side. – 0905057CCC2610

JOINT ANALYSIS RESULTS:
ADDITIONAL CRASH AVOIDANCE FEATURES

* 1% not applicable (2/171)

Inconclusive:

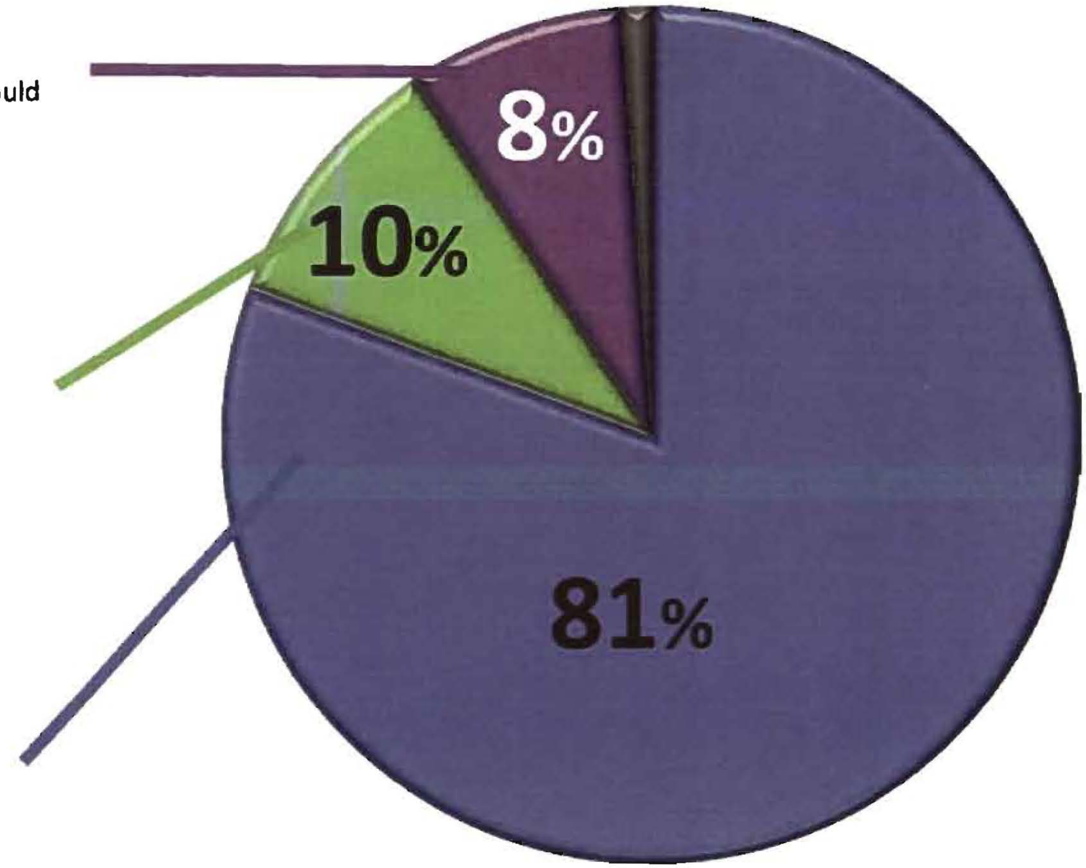
It is possible, but unclear, that different design attributes could have mitigated the crash

Insufficient Information:

There is insufficient information known about the crash scenario to draw a conclusion about the effect of different crash avoidance attributes

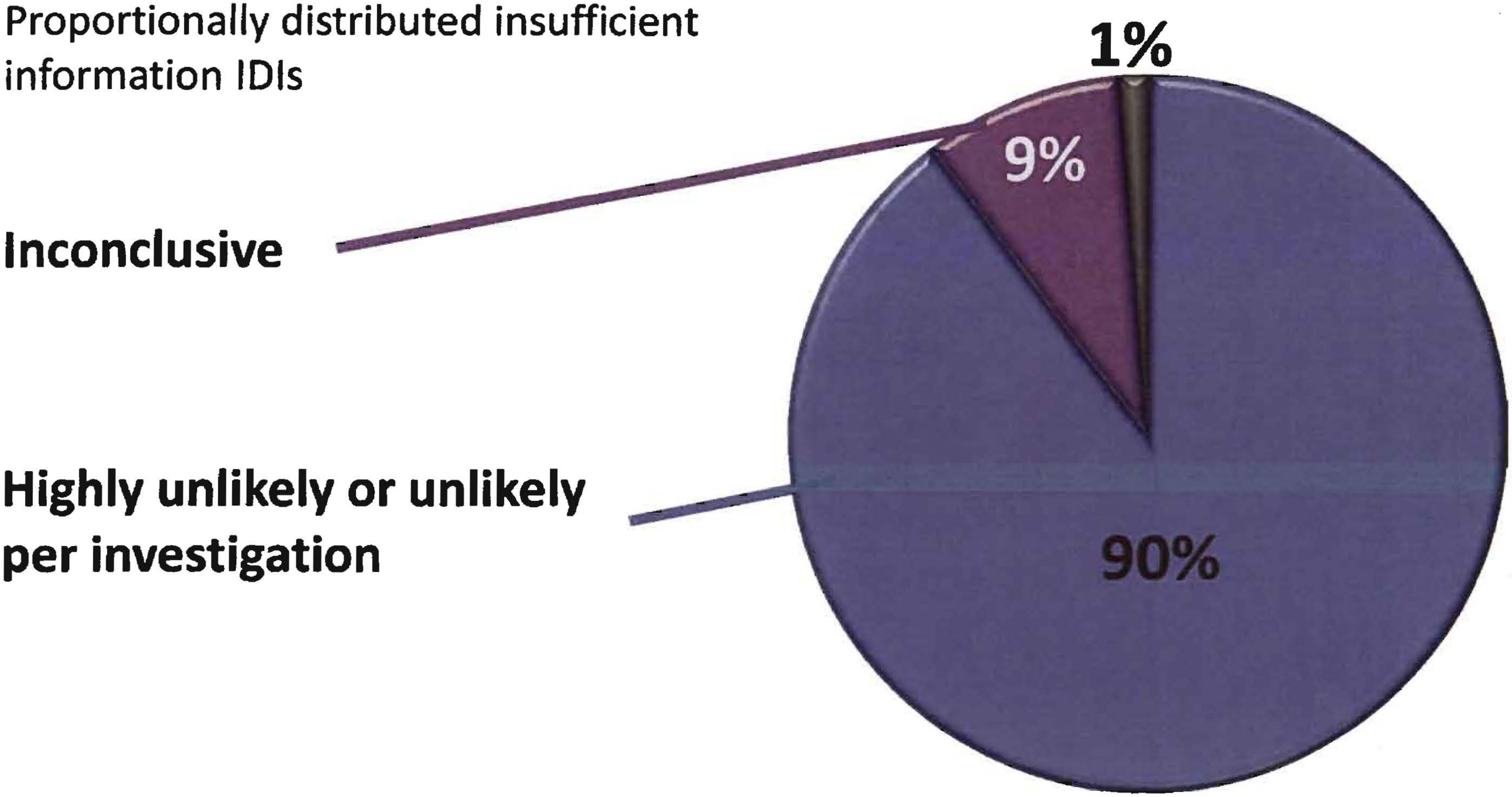
Highly Unlikely/Unlikely:

The circumstances of the crash were unrelated to the crash avoidance capacities of the machine, the operator was intentionally engaging in risk-taking behavior or stunts, or the authority or agency investigating the accident concluded that the operator was making unreasonable and/or inappropriate driving decisions



JOINT ANALYSIS RESULTS: EFFECT OF ADDITIONAL CRASH AVOIDANCE FEATURES

Proportionally distributed insufficient information IDIs



* 1% not applicable

SUMMARY STATISTICS

Crash Avoidance	Percent
Unlikely/Highly unlikely	90
Inconclusive	9
Not applicable	1

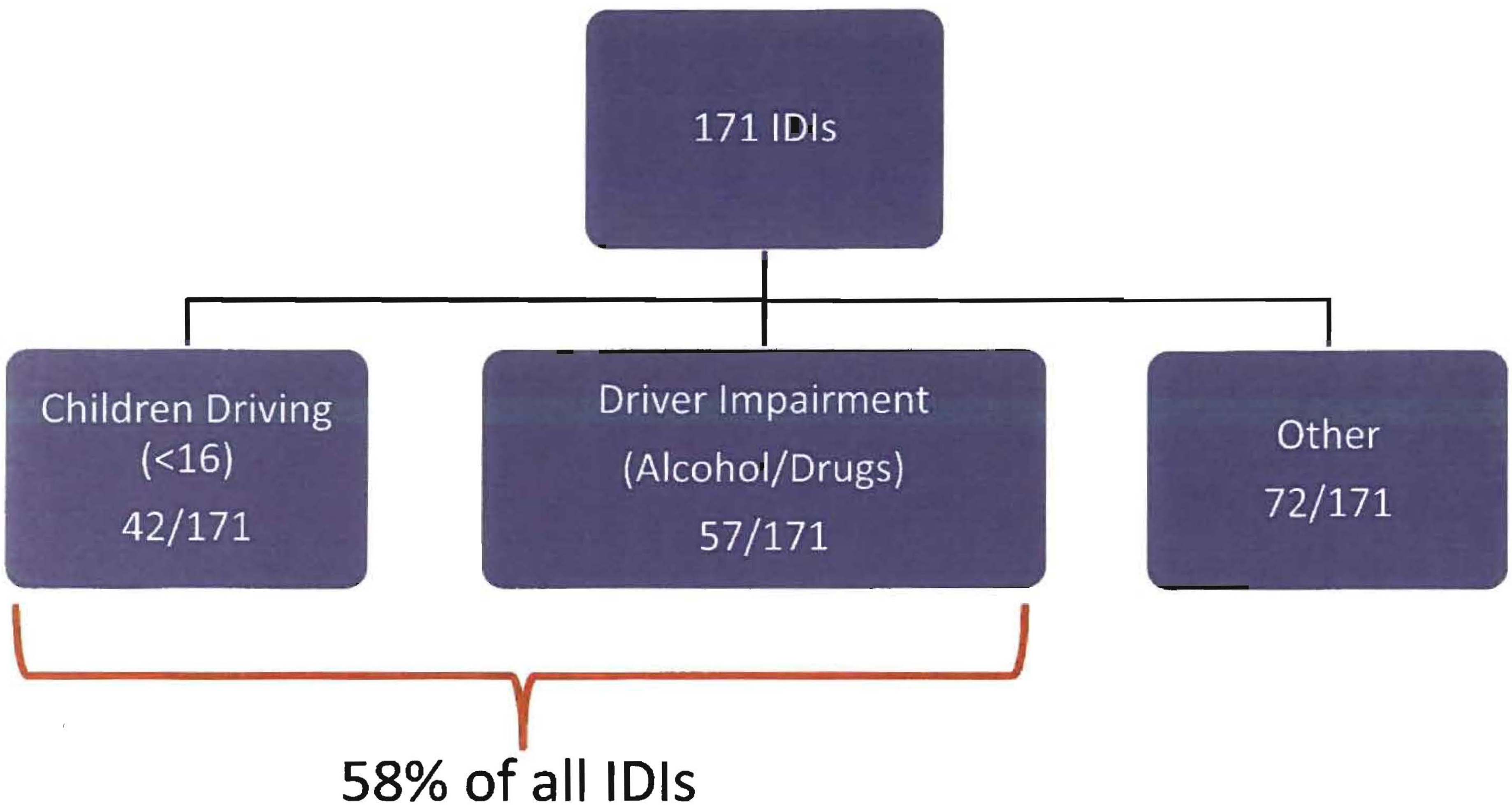
Proportionally distributed Insufficient Information IDIs

ADDITIONAL HUMAN FACTORS ANALYSIS

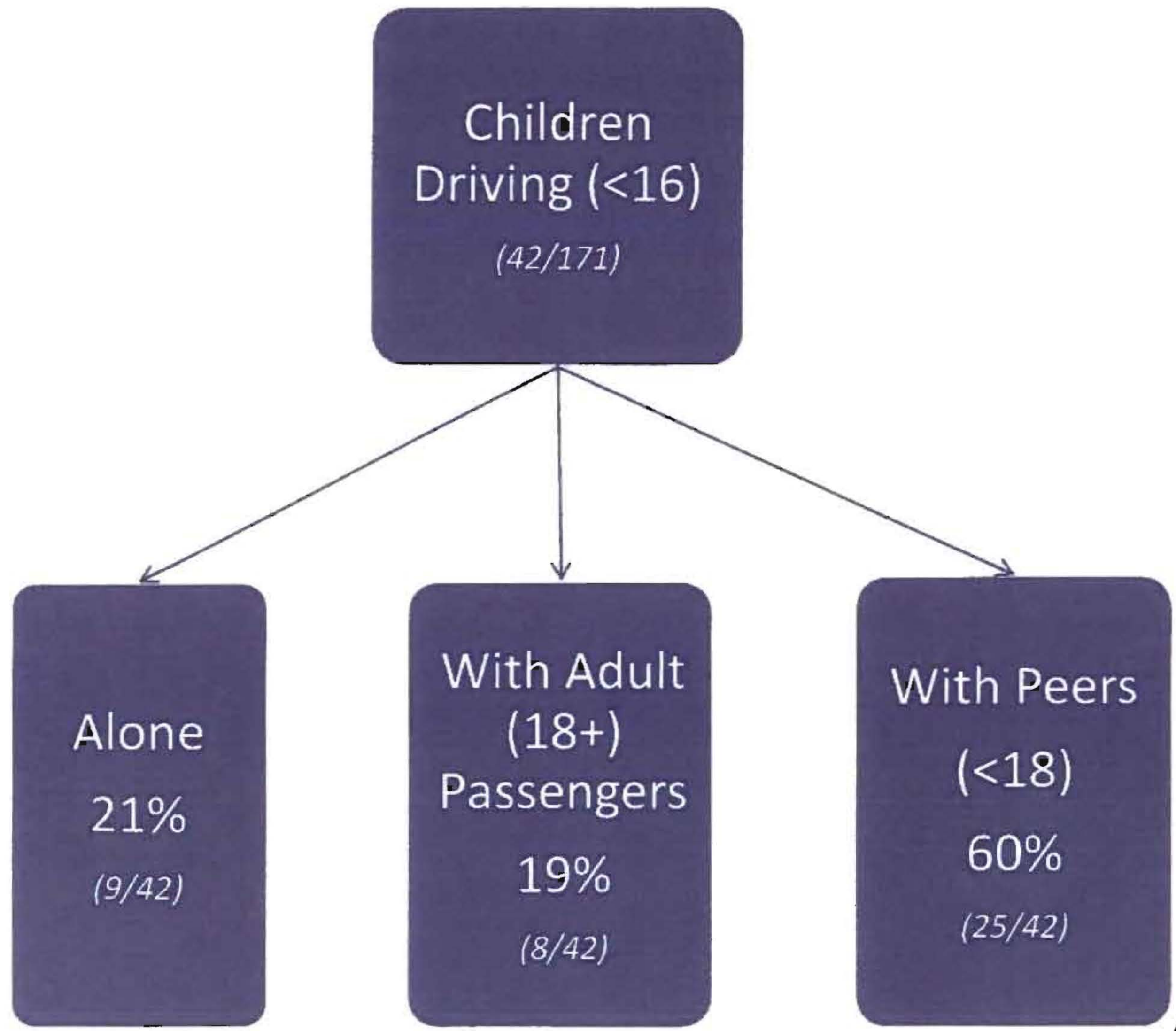
- Review of over 70 factors associated with IDIs
- Examples factors include:
  - Indication of Legal Violations (Ex. Felonies and Misdemeanor offenses)
  - Driver & Passenger Age
  - Number of Passengers
  - Goal of Operation
  - Alcohol Use & Levels
  - Location of Passengers
  - Location of Use
  - Accident Terrain

APPLIED SAFETY + ERGONOMICS

IDI Breakdown



WHEN CHILDREN UNDER 16 DRIVE, WHO IS IN THE VEHICLE WHEN THEY CRASH?



APPLIED SAFETY + ERGONOMICS

Incidents with Known Driver Blood Alcohol Content Level